INTRODUCTION TO COMPUTABLE GENERAL EQUILIBRIUM MODELS

This book provides an accessible, undergraduate-level introduction to computable general equilibrium models, a class of model that has come to play an important role in government policy decisions. The book uses a graphical approach to explain the economic theory that underlies a CGE model, and provides results from simple, small-scale CGE models to illustrate the links between theory and model outcomes. The book includes eleven guided, hands-on exercises that introduce modeling techniques that are applied to real-world economic problems. Students learn how to integrate their separate fields of economic study into a comprehensive, general equilibrium perspective as they develop their skills as producers or consumers of CGE-based analysis.

Mary E. Burfisher is Senior Education Advisor at the Center for Global Trade Analysis at Purdue University and an adjunct professor in the Business and Finance program at the University of Maryland University College. Dr. Burfisher was a Distinguished Visiting Professor at the United States Naval Academy in Annapolis, Maryland; she spent much of her career as an economist at the United States Department of Agriculture. She earned her Ph.D. in economics from the University of Maryland.

INTRODUCTION TO COMPUTABLE GENERAL EQUILIBRIUM MODELS

SECOND EDITION

MARY E. BURFISHER

CAMBRIDGE
UNIVERSITY PRESS

CAMBRIDGE
UNIVERSITY PRESS

One Liberty Plaza, 20th Floor, New York, NY 10006, USA

Cambridge University Press is part of the University of Cambridge.

It furthers the University's mission by disseminating knowledge in the pursuit of education, learning, and research at the highest international levels of excellence.

www.cambridge.org
Information on this title: www.cambridge.org/9781107132207

First published 2016

Printed in the United States of America by Sheridan Books, Inc.

A catalogue record for this publication is available from the British Library

Library of Congress Cataloging-in-Publication Data
Names: Burfisher, Mary E., author.
Title: Introduction to computable general equilibrium models / Mary E. Burfisher, Center for Global Trade Analysis, Purdue University.
Description: New York, NY : Cambridge University Press, [2016] | Earlier edition: 2011. | Includes bibliographical references and index.
Identifiers: LCCN 2016036247 | ISBN 9781107132207 (hardback : alk. paper) | ISBN 9781107584686 (pbk. : alk. paper)
Subjects: LCSH: Computable general equilibrium models. | Equilibrium (Economics) – Mathematical models.
Classification: LCC HB145 .B86 2016 | DDC 339.501/5195 – dc23
LC record available at https://lccn.loc.gov/2016036247

ISBN 978-1-107-13220-7 Hardback
ISBN 978-1-107-58468-6 Paperback

For my family

Contents

Text Boxes

Acknowledgments

This book was made possible by the support of three institutions. I am deeply grateful to the National Science Foundation and especially to Dr. Myles G. Boylan, Program Director in the Course, Curriculum and Laboratory Improvement Program of the Division of Undergraduate Education, for their support of a project to introduce students at the undergraduate level to applied tools in general equilibrium analysis. I also want to thank the United States Naval Academy, where I was privileged to be a Distinguished Visiting Professor while writing the first edition of this book. I owe a special thanks to my students at the Naval Academy, who were the first users of this material and who provided useful feedback and many good ideas. The Global Trade Analysis Project (GTAP), particularly Thomas Hertel, Angel Aguiar, Ginger Batta, Jeremy Douglas, Badri Narayanan, and Terrie Walmsley, have been generous in their support of this project and of "GTAP-101," the Center's online course based on this book. I thank Mark Horridge at Victoria University in Melbourne, who has helped me with many modeling challenges. I am deeply grateful to my longtime CGE colleagues, Karen Thierfelder and Sherman Robinson, from whom I have learned so much about this subject. I also thank Jayson Beckman, who developed the ESUBr toy model for this book, and to Shawn Arita, for generously sharing his knowledge on the analysis of NTMs; both were my valued colleagues at the USDA. I owe a special thanks to Victoria Greenfield, who provided insightful critiques and many suggestions and substantive edits on early drafts of the book, and I extend my grateful appreciation to Kurtis Swope and Katherine Smith – my colleagues at the Academy – who acted as beta testers and reviewers of the first edition. My editors Scott Parris and Karen Maloney at Cambridge University Press facilitated both editions of this book in every way. I want to recognize the exceptional work of my meticulous research assistant, Henry Jacobs, for his careful, capable, and thoughtful review and double-checking of the second edition of the book. Many other colleagues and students also have generously provided valued feedback, corrections, and ideas for the first and second editions of this book. I particularly thank Channing Arndt, Andre Barbe, François Delorme, Hannah Derringer, Sunil Dhoubhadel, Barry Krissoff, Rob McDougall, Birgit Meade, Alan Mehlenbacher, Peter Minor, John Moon, Takeshi Mori, Maria de la Conception Latorre Munoz, Ana Norman, Luciana Porfirio, Kathy Ralston, Marie Louise Rau, Jeffrey Round, Enkhbayar Shagdar, Marcelle Thomas, Marinos Tsigas, Dominique van der Mensbrugghe, Frank van Tongeren, and my students in GTAP 101 and the CGE Cloudclassroom. Finally, I thank six anonymous reviewers who provided many helpful suggestions on earlier drafts. All remaining errors are my own responsibility, and I encourage readers to contact me about them or to offer their comments or suggestions on the book.

Note: This material is based on activities supported by the National Science Foundation under Agreement No. DUE-0632836. Any opinions, findings, and conclusions or recommendations expressed are those of the author and do not necessarily reflect the views of the National Science Foundation.

About This Book

Objectives

This book will introduce you to computable general equilibrium (CGE) models. A CGE model is a powerful analytical tool that can help you gain a better understanding of real-world economic issues. CGE models are a class of economic model that over the past three decades has gained widespread use in the economics profession, particularly in government. Economists today are using these models to systematically analyze some of the most important policy challenges and economic "shocks" of the twenty-first century, including global climate change, trade agreements, the spread of human diseases, and international labor migration.

Since the early 1990s, prominent CGE models have been built and maintained at the U.S. International Trade Commission, the Economic Research Service of the U.S. Department of Agriculture, the World Bank, and other national agencies and international organizations to provide ongoing economic analytical capability. These models have come to play an important part in government policy decisions worldwide. For example, the models' predictions about prices, wages, and incomes factored heavily in the debate about the terms of the North American Free Trade Agreement, the Kyoto Protocol, China's entrance into the World Trade Organization and the Trans-Pacific Partnership. CGE-based analyses have also helped the proposed United States and other governments anticipate and design responses to substantial changes in the availability of key resources, ranging from petroleum to people.

CGE models are comprehensive because – whether they are detailed or very simplified – they describe all parts of an economy simultaneously and how these parts interact with each other. The models describe the efficiency-maximizing behavior of firms and the utility-maximizing behavior of consumers. Their decisions add up to the macroeconomic behavior of an economy, such as changes in gross domestic product (GDP), government tax revenue and spending, aggregate savings and investment, and the balance of trade. As might be expected, such models can require large databases and they contain sophisticated model code. Yet despite their complexity, continuing advances in modeling software and database development are making CGE models increasingly accessible and intuitive. Minimizing the technical entry barriers to CGE modeling has freed economists to focus on the models' economic behavior and the economic insights that can be derived from their results. These innovations have also made CGE models an ideal laboratory in which economics students can learn to manipulate, observe, and deepen their knowledge of economic behavior.

This book is designed to provide a hands-on introduction to CGE models. You will draw on theory from microeconomics, macroeconomics, international trade and finance, public finance, and other areas of economics, as you observe how producers and consumers in the CGE model respond to various changes in market conditions that we refer to as "model experiments." The guided model exercises will show you how to build and use a demonstration CGE model to assess the economy-wide effects of such economic shocks as the elimination of agricultural subsidies and trade barriers, labor immigration, and changes in a tax system. By the end of the book, you will have begun to develop your skills as both a producer and a consumer of professional CGE-based economic analysis.

The book introduces the CGE models and databases that are used by professional economists. We will study the key features of "standard" CGE models, which are static (single period), single- and multi-country models, with fixed national endowments of factors of production. Most textbook examples and model exercises use RunGTAP, a user-friendly, menu-driven interface (Horridge, 2001) of the GTAP (Global Trade Analysis Project) CGE model. RunGTAP may be downloaded at no charge from the GTAP Web site (Prologue Table 1). The GTAP CGE model is an open model developed by Hertel and Tsigas (1997) and is written in the GEMPACK software language.

Prologue Table 1. *Modeling and Data Resources Used in This Book*

Resource	Source
RunGTAP CGE model	Download from GTAP.org
GTAPAgg81y07 database aggregation utility	Download from GTAP.org
US3×3 database	Create using GTAPAgg81y07
US3×3 model	www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=4841
Small pedagogical CGE models	www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=4841

The GTAP project also maintains a global database that CGE modelers rely on as a data source for many types of CGE models. The database is built from data contributions by CGE modelers around the world, which GTAP then organizes and balances into a consistent, global database. The 8.1 version of the database, used for demonstration in this book, describes 134 countries or regions and 57 industries in 2007. Modelers may use GTAPAgg, a freeware program developed by Horridge (2015a) and available from the GTAP project, to aggregate the global database into smaller sets of regions and industries that are relevant for their research. In this book and in the model exercises, most examples use a small-dimension, two-region aggregation of the database that describes the United States and an aggregate rest-of-world region.

What's New in the Second Edition

Revisions in the second edition include an updated database and recent additions to CGE research literature, and respond to student requests for additional explanations and coverage of new topics. These are the main changes:

- Demonstration database and model exercises are updated to GTAP's version 8.1 (2007) database.
- A new section on preferential tariffs is added to Chapter 8 – Taxes in a CGE Model.
- A new Chapter 9 is added to describe the analysis of regulations, including non-tariff measures in international trade and corrections of production externalities.
- Two new model exercises provide hands-on guidance in carrying out an integrated assessment of climate change impacts and removal of non-tariff measures.
- The US3×3 CGE model and database used for the textbook are available for download from the GTAP Web site. Students may review and replicate the experiments that are reported in this book's tables. The download address is: www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=4841.
- Additional "toy" models used to explore taxes (TaxToy), preferential trade agreements (PTAToy), and Armington and factor substitution elasticities defined by region (ESUBrToy) are available for download from the same GTAP Web page. Students may review and replicate the model experiments reported in the text and use the models to carry out their own stylized research.
- Other updates and additions appear throughout the book, including sections on nonlinear and linearized equations, price transmission, selection and evaluation of elasticity parameters, and recent, influential examples of CGE-based analyses.

Organization

This book covers nine topics, beginning with an introduction to CGE models (Chapter 1), their elements and structure (Chapter 2), and the data that underlie them (Chapter 3). Chapters 4–6 focus on the microeconomic underpinnings of CGE models. Chapter 4 describes final demand by households, government, and investors; the demand for imports and exports; and welfare measurement. Chapter 5 describes supply, focusing on the technology tree and the producer's cost-minimizing demand for intermediate and factor inputs. Chapter 6 covers additional aspects of factor markets, including factor mobility, factor endowment and productivity growth, factor substitutability, and factor employment assumptions. Trade topics, including theorems on the effects of endowment changes and world prices, are covered in Chapter 7. Chapter 8 explores public finance topics related to trade and domestic taxes, including preferential tariffs. Chapter 9 presents the economic theory of two types of regulations, non-tariff trade measures and the correction of production externalities, and explains how these regulations are analyzed in a CGE model.

Chapters 1–9 adhere to a common template, consisting of:

- Chapter text (e.g., "Introduction to Computable General Equilibrium Models")
- Text boxes
- Chapter summary
- Key terms (e.g., "stock" and "flow")
- Practice and review exercises
- Model exercise

Text boxes introduce examples of classic, innovative, and influential CGE-based economic analyses that relate to chapter topics. These summarized articles offer practical examples of how the concepts that you are learning about in the chapter are operationalized in CGE models. Practice and review exercises review and reinforce the central themes of the chapter.

Model exercises linked to each chapter provide step-by-step direction and guidance to help you develop your modeling skills (Prologue Table 2). The modeling problems are general enough to be suitable for use with almost any standard CGE model, but their detailed instructions are compatible with RunGTAP. The first three model exercises guide you in creating a database, setting up your CGE model, and learning core modeling skills. You may use the demonstration model developed in the first model exercise to replicate almost all results reported in the tables in Chapters 1–9 of the book. Exercises 4–11 are case studies that begin with a discussion of a timely topic or influential CGE analysis such as labor immigration and U.S. tax policies. They demonstrate how to design model experiments and how to use economic theory to select and interpret model results. Two are "challenge exercises" that introduce advanced students to baseline scenarios, updates of tax data, and uncertainty about elasticity parameters and economic shocks.

Prologue Table 2. *Chapters and Related Model Exercises*

Chapter	Model Exercise
1. Introduction to CGE Models	Set up the GTAP Model and Database
2. Elements of a CGE Model	Explore the GTAP Model and Database
3. The CGE Model Database	Run the GTAP Model
4. Final Demand in a CGE Model	(1) Soaring Food Prices and the U.S. Economy (2) Successful Quitters: The Economic Effects of Growing Antismoking Attitudes *(Challenge)*
5. Supply in a CGE Model	Food Fight – Agricultural Production Subsidies
6. Factors of Production in a CGE Model	(1) How Immigration Can Raise Wages (2) Climate Change – the World in 2050
7. Trade in a CGE Model	The Doha Development Agenda
8. Taxes in a CGE Model	The Marginal Welfare Burden of the U.S. Tax System
9. Regulations in a CGE Model	Deep Integration in the T-TIP *(Challenge)*

Resources for New CGE Modelers

We recommend that beginning modelers start by reading articles and monographs, both current and classic, that provide general introductions to, or critiques of, CGE models. Particularly recommended as introductory treatments are Piermartini and Teh (2005), McDaniel et al. (2008), Shoven and Whalley (1984), Bandara (1991), Francois and Reinert (1997), Robinson et al. (1999), Devarajan et al. (1990, 1997), and Borges (1986). Breisinger, Thomas, and Thurlow (2009), Reinert and Roland-Holst (1992), and King (1985) provide introductions to social accounting matrices, which are the databases that underlie CGE models.

As your skills progress, we recommend that you read intermediate-level treatments of CGE models. Perhaps the most important of these is the collection of articles by distinguished CGE modelers in the *Handbook of Computable General Equilibrium Modeling*, edited by Dixon and Jorgenson (2013). Kehoe and Kehoe (1994) provide a primer on CGE models and Dervis, deMelo, and Robinson (1982) offer an introduction to open economy CGE models. Hosoe, Gasawa, and Hashimoto (2010) introduce students at an intermediate level to CGE models, focusing on models coded in General Algebraic Modeling Software (GAMS). Some books and articles that describe specific CGE models are also useful for new modelers, who will recognize many of the same features in those models as in the standard CGE model that we study in this book. Hertel and Tsigas (1997) provide an overview of the GTAP model. Lofgren, Harris, and Robinson (2002) describe the International Food Policy Research Institute's (IFPRI) standard single-country CGE model and database. DeMelo and Tarr (1992) describe the structure and behavior of their CGE model of the United States. Thierfelder and McDonald (2011) describe the multi-country GLOBE CGE model. For more advanced students, Shoven and Whalley (1992) provide a practical introduction to CGE models, and Scarf and Shoven (2008) present a collected volume of case studies that describe different aspects of CGE models.

Because CGE modeling is a dynamic field of research, the best way to keep abreast of developments in CGE modeling and in the applications of CGE models is to review working papers and conference papers, in addition to economic journals. The GTAP Web site (www.gtap.org) is a useful source for up-to-date information on CGE-based research papers, CGE model databases, and research tools and utilities related to the GTAP model and data. All papers presented at annual GTAP conferences are posted online, providing students with access to unpublished papers and work in progress by many leading CGE modelers using many types of CGE models. Perusing recent conference papers can give you ideas for timely research topics and experiment designs for your own research projects.

The International Food Policy Research Institute (IFPRI), which developed the “IFPRI standard” CGE model, has published many studies based on variations of that model as well as papers about model databases and database construction. These publications are available from the IFPRI Web site at www.ifpri.org.

Many international organizations, such as the World Bank, and national government agencies, such as the U.S. Department of Agriculture, also produce and post CGE-based working papers and research products. In addition, the GAMS Web site (www.gams.org) maintains a library of simple CGE models that can be downloaded and run using the free demonstration version of GAMS. Also, the United States Naval Academy hosts the Tools for Undergraduates “TUG-CGE” model (Thierfelder, 2009), a GAMS-based CGE model designed for undergraduate pedagogical use.

For the Instructor

The book is designed for use in a one-semester class that is spent primarily doing hands-on model exercises and independent research, with the book used as background reading. The exercises are all fully portable. They are designed to use free materials downloaded from the Internet so they are suitable for students to carry out in computer labs or on their personal computers. The ideal classroom setting is one that promotes student teamwork and ongoing discussion among students and teachers while students carry out model exercises.

Prologue Table 3. *Recommended Sequences for Courses of Different Lengths*

Chapter	One Semester Course	6-Week Course	1-Week Course
1. Introduction to CGE Models	0.5 weeks	0.5 weeks	Omit
2. Elements of a CGE Model	1 week	0.5 weeks	0.25 day
3. CGE Model Database	1 week	1 week	0.5 day
4. Demand in a CGE Model	1.5 weeks	0.5 weeks	0.5 day
5. Supply in a CGE Model	1 week	0.5 weeks	0.5 day
6. Factors of Production in a CGE Model	1 week	Optional	Omit
7. Trade in a CGE Model	1 week	0.5 weeks	0.5 day
8. Taxes in a CGE Model	1 week	0.5 weeks	0.5 day
9. Regulations in a CGE Model	1 week	Optional	0.25 day
Independent Research	6 weeks	2 weeks	2 days

The book can also be used in condensed courses, with our recommendations for selecting and paring materials described in Prologue Table 3. For courses of all lengths, we recommend a generous allotment of time for model exercises and independent research, because students will then learn by doing. If the book is used as a supplementary hands-on resource for economic theory courses, such as macroeconomics or international trade, we suggest that the teacher cover Chapters 1–3 and their related model exercises and then assign only the chapter and exercise that is relevant to the course. Most teachers are likely to find that some or all of Chapter 8 on taxes is relevant because taxes are a policy lever that governments use to address many economic problems.

1

Introduction to Computable General Equilibrium Models

This chapter introduces students to computable general equilibrium (CGE) models, a class of economic model that describes an economy as a whole and the interactions among its parts. The basic structure of a CGE model and its database are described. We introduce a "standard" CGE model and provide a survey of CGE model applications.

Economic Models, Economists' Toys

When an economist wants to study the economic behavior observed in the complex world around us, the first step is often to build an economic model. A model can focus an analysis by stripping down and simplifying real-world events into a representation of the motivations of the key players in any economic story. Some amount of context and interesting detail must be left out as the economist distills a model rich enough to explain events credibly and realistically but simple enough to put the spotlight on the essential actions in the story. When an economist succeeds in building a model, he or she now has a tool that can be manipulated. By playing with this "toy" representation of economic activity, the economist can learn more about the fundamentals behind an event and can study likely outcomes or possible solutions.

There are many kinds of economic models. The type of model that we will be studying is a *computable general equilibrium (CGE)* model. It is an "economy-wide" model because it describes the motivations and behavior of all producers and consumers in an economy and the linkages among them. It depicts firms that respond to demand by purchasing inputs, hiring workers, and using capital equipment. The income generated from sales of firms' output ultimately accrues to households, who spend it on goods and services, taxes, and savings. Tax revenue funds government spending and savings lead to investor spending. The combined demand by private households, government, and investors is met by firms that, to complete the *circular flow of income and spending*, buy inputs and hire workers and capital used in their production processes. Such a comprehensive model may seem to be very complex, but we hope that its deconstruction in the following chapters will reveal it to be a relatively simple, "toy" representation of our complex world.

As a point of departure for our study, we begin by examining a toy partial equilibrium model. Suppose we are asked to build an economic model to analyze the supply and demand for bicycles. We can draw on our microeconomic theory to introduce a supply equation to describe bicycle production. First, we use general functional notation to express that the quantity of bicycles that producers supply, QO, is related to the prices of bicycle inputs, P_i, such as rubber tires, and the market price of bicycles, P. With this general functional notation, we know only that there are causal relationships between output and price variables but not their sizes or whether they are positive or negative. We can also draw on microeconomic theory to introduce a demand equation. Again using general notation, we express that the quantity of bicycles that consumers demand, QD, is a function of their income, Y, and the price of bicycles. Finally, we know from economic theory that a market economy will tend toward market-clearing; that is, the price of bicycles will adjust until the quantity that producers supply equals the quantity that consumers demand. To describe this equilibrium in the model, we introduce the *market-clearing constraint*, $Q = QO = QD$; the equilibrium quantity of bicycles supplied and demanded must be equal.

The three equations describing the bicycle industry model, expressed in general functional notation, are listed in Table 1.1. The model has two *exogenous* variables: input prices, P_i, and consumer income, Y. Their values are determined by forces outside the model, and we take them as given. The model has two *endogenous* variables: the equilibrium quantity, Q, and the

Table 1.1. *Bicycle Industry Model*

Model Equations		
Type	General Notation	Numerical Function
Supply equation:	$QO = G(P_i, P)$	$QO = -4P_i + 2P$
Demand equation:	$QD = F(P, Y)$	$QD = 2Y - 2P$
Market clearing constraint:	$Q = QO = QD$	
Endogenous Variables		
Q = Quantity of bikes		
P = Price of bikes		
Exogenous Variables		
P_i = Prices of inputs (e.g., tires, steel)		
Y = Income		

price, P, of bicycles. Their values will be determined as solutions to our model's equations.

Using our bicycle industry model with general functional notation, we can draw these qualitative conclusions about the effects of changes in our exogenous variables on the endogenous variables: A change in income, Y, will affect the quantity of bicycles that consumers demand, while a change in input prices, P_i, will affect the quantity of bicycles that producers supply. Given our market-clearing constraint, a change in either exogenous variable will lead to a change in the price of bikes until the quantities of bikes that are supplied and demanded are again in equilibrium.

Our model becomes more useful if we have sufficient data on the supply and demand for bicycles to estimate the sign and size of the relationships among the variables. We can then express our model equations in specific and numerical functional form, such as $QD = 2Y - 2P$, which is a linear demand function. With this information, we can now say that the quantity of bicycles demanded can be calculated as two times income minus two times the price of bicycles. Perhaps we also estimate this linear supply function for bicycle supply: $QO = -4P_i + 2P$. We now have a quantitative model that describes both demand and supply and is capable of yielding numerical solutions.

If we are now given values for our exogenous variables, Y and P_i, we can solve our model to find the initial, market-clearing values for the two endogenous values, P and Q. If, for example, we know that the value of Y is 10 and P_i is 4, then we can substitute these values into our equations and solve. The market-clearing quantity should be two bicycles at a price of $9 each.

We can learn a great deal about the bicycle industry by using the model to conduct a model experiment. We carry out an experiment by changing an exogenous variable in the model, Y or P_i. When we change one exogenous variable at a time, we are using our model of the bicycle industry to conduct a controlled experiment. This "what-if" scenario helps us isolate and understand the role of a single factor, such as income, in explaining the changes in the bicycle quantities and prices that we observe in our model. We can also now offer quantitative conclusions, such as: "If we double income, bicycle production will increase to twelve and the price of bicycles will rise to $14."

What Is a Computable General Equilibrium Model?

A CGE model is a system of equations that describes an economy as a whole and the interactions among its parts. Despite its comprehensiveness, it is much like the bicycle model. It is based on equations derived directly from economic theory, which will look familiar to students from their courses in microeconomics and macroeconomics. The equations may describe producers' supply or consumer demand, or be familiar macroeconomic identities such as GDP = C + I + G + E – M. Like the bicycle model, a CGE model includes exogenous and endogenous variables and market-clearing constraints. All of the equations in the model are solved simultaneously to find an economy-wide equilibrium in which, at some set of prices, the quantities of supply and demand are equal in every market.

To conduct experiments with a CGE model, the economist changes one or more exogenous variables and re-solves the CGE model to find new values for the endogenous variables. The economist observes how the exogenous change, or "economic shock," affects the market equilibrium, and draws conclusions about the economic concern under study – be it a rise in the price of bicycle tires, or fuel, or labor immigration.

A CGE model differs from our model of the bicycle industry because it represents the whole economy, even if at times in a very stylized and simplified way. A CGE model describes production decisions in two or more industries – not just one, as in the bicycle model. A CGE model also includes demand for all goods and services in the economy, not just for bicycles. While the *partial equilibrium* model assumes income and prices in the rest of the economy are fixed, a CGE model describes how changes in the demand and supply for a good such as bicycles can lead to changes in employment and wages, and therefore in households' income and spending. It also describes changes in prices for other goods and services in the economy, such as bicycle inputs and the products that compete with bicycles in consumer demand. A CGE model also includes all sources of demand, not only from producers and private households but also from other economic agents – the government, investors, and foreign markets. Because a CGE model depicts all of the microeconomic activity in an economy, the summation of these activities describes the macroeconomic behavior of an economy, including its gross domestic product (GDP), aggregate savings and investment, the balance of trade, and, in some CGE models, the government fiscal deficit or surplus.

We can learn more about the basic features of a CGE model by considering the meaning of each component of its name: "computable," "general," and "equilibrium."

Computable

The term *computable* in CGE models describes the capability of this type of model to quantify the effects of a shock on an economy. As an economist, you can generally rely on economic theory to help you anticipate a directional change. For example, if you are asked to describe the expected effect of a reduction in a U.S. tariff, you are likely to argue that it will lower the domestic price of the import, leading to an increase in the quantity of demand for imports and a decrease in the quantity of demand for the domestic, import-competing variety. However, policy makers or industry advocates may want to know if this effect will be large or small.

The equations of a CGE model utilize data for an actual economy in some base year, such as the U.S. economy in 2016. In this case, the utility functions incorporate data on U.S. consumer preferences in 2016. The production function for each industry is based on U.S. firms' technology – inputs and production levels – in 2016. Because the equations in a CGE model incorporate real data about an actual economy, the model's new equilibrium values following an experiment enable you to quantify in a realistic way the anticipated value of the impact on the economy, such as a $25 million or $2.5 billion change in an industry's output.

The ability to quantify the values associated with the outcomes of various "what if" scenarios allows the economist to make a powerful contribution to debates about economic policy. CGE modelers have provided influential analyses of the costs and benefits of government policies, such as trade agreements like NAFTA, emissions control programs, and the agreement to admit China into theWorld Trade Organization (WTO). CGE models have also been used to quantify the effects of market shocks including oil price hikes and labor migration.

General

In a CGE model, the term *general* means that the model encompasses *all* economic activity in an economy simultaneously – including production, consumption, employment, taxes and savings, and trade – and the linkages among them. For example, if higher fuel prices change the cost of producing manufactured goods such as bicycles, books, cars, and TVs, then the prices of these goods will rise. The demand response of consumers will lead to changes throughout the economy. For example, consumers may buy fewer bicycles, cars, and TVs, but buy more Kindles and e-books. The changes in consumer demand and industry output will then affect employment, incomes, taxes, and savings. In an open economy, the fuel price hike also may lead to changes in trade flows and in the exchange rate; the latter is a macroeconomic shock that will in turn affect the whole economy.

One way to depict the interrelationships in a CGE model is to describe them as a circular flow of income and spending in a national economy, as shown in Figure 1.1. You may recall this circular flow diagram from your macroeconomics class. To meet demand for their products, producers purchase inputs such as rubber tires and bicycle seats. They also hire factors of production (labor and capital) and pay them wages and rents. The factor

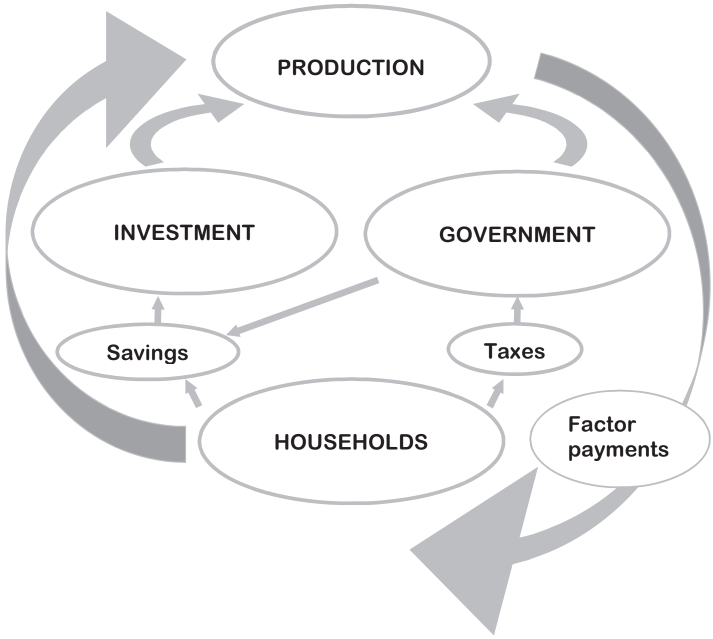


Figure 1.1. The circular flow of income and spending in a national economy.

payments ultimately accrue to private households as wage and capital rental income. Households spend their income on goods and services, pay taxes to the government, and put aside savings. The government uses its tax revenue to buy goods and services, and investors use savings to buy capital investment goods for use in future production activities. The combined demand for goods and services from households, government, and investment constitutes final demand in the economy. Firms produce goods and services in response to this demand, which in turn determines input demand, factor employment levels, households' wage and rental income, and so forth, in a circular flow. If we introduce trade into this circular flow, we would account for the role of imports in meeting some of the domestic demand, and we would add export demand as an additional source of demand for domestic goods. Finally, we can think of policies such as taxes and subsidies as "price wedges" that increase or lower the prices of goods between buyers and sellers, or as transfers that directly affect households' level of income and therefore their levels of consumption, savings, and taxes.

A general equilibrium model describes all of these interrelationships in an economy at once: "Everything depends on everything else." An important caveat to "everything" is that CGE models are "real" models. A real model does not include money, describe financial markets or changes in overall price levels (like inflation or deflation), or reflect the effects of monetary policy such as an increase in the money supply. Instead, a real model measures all variables in terms of physical quantities and the relative prices at which goods are exchanged for each other, such as three books per DVD.

It is likely that most of your economics coursework so far has presented partial equilibrium models. A partial equilibrium model describes economic motives and behavior in one industry, such as the bicycle industry, or of one type of economic agent, such as consumers, and holds prices and quantities in the rest of the economy constant. A partial equilibrium analysis is similar to placing a magnifying glass over one part of the economy and assuming that the action in the rest of the economy is either not important or not changing at the moment. This focus on a specific part of the economy allows economists to develop richly detailed analyses of a particular industry or economic activity, but the trade-off is that important, interdependent links with the rest of the economy are not taken into account. These linkages are particularly important if the industry or other aspect of economic activity under study is large relative to the rest of the economy.

Equilibrium

An economy is in *equilibrium* when supply and demand are in balance at some set of prices, and there are no pressures for the values of these variables to change further. In a CGE model, equilibrium occurs at that set of prices at which all producers, consumers, workers, and investors are satisfied with the quantities of goods they produce and consume, the industry in which they work, the amount of capital they save and invest, and so forth. Producers have chosen input and output levels that have *maximized their efficiency* given the costs of inputs such as fuel and equipment, their sales prices, and the technological constraints of their production processes. Consumers have *maximized their utility*, or satisfaction, by purchasing the most satisfying bundle of products – such as books, bicycles, cars, and TVs – given their budgets and the prices of consumer goods. The CGE model's equilibrium must also satisfy some important macroeconomic, market-clearing constraints; generally these require that the aggregate supply of goods and services equals aggregate demand, all workers and the capital stock are employed, and national or global savings equals investment spending.

The CGE modeler conducts an experiment by creating "disequilibrium" – that is, by changing an exogenous variable in the model. For example, the modeler may specify an increase in an import tariff. This shock will change the economy – consumers are likely to buy fewer imports and more of the domestic product, and domestic firms are likely to expand their production to meet growth in demand. When running a model experiment, the CGE modeler is like a billiard player who hits one ball, causing reactions and interactions among all of the balls on the table, and who must wait to see where all the balls come to rest. All of the CGE model equations must be re-solved to find new solution values for all of the endogenous variables in the model. The new values represent a new equilibrium in which the quantities of supply and demand are again equal at some set of prices. The CGE model that we will study does not show the adjustment process; we do not watch as the billiard balls knock against each other as they traverse the table. This is an important point to keep in mind as you use a CGE model to conduct policy analysis.

A Standard CGE Model

CGE models come in all shapes and sizes. Despite this diversity, most models share the same core approaches to depicting supply and demand, factor markets, savings and investment, trade, and taxation and regulations. In this book, we concentrate on these shared, core elements as we introduce you to a "standard" CGE model, which is a static (single-period), single or multi-country CGE model with a fixed endowment of factors of production, such as labor and capital.

A *static* CGE model provides a before- and after-comparison of an economy when a shock, such as a tax, causes it to reallocate its productive resources in more or less efficient ways. Static models can tell a powerful story about the ultimate winners and losers from economic shocks. However, a noteworthy drawback is that they do not describe the adjustment path. The adjustment process may include periods of unemployment and dislocation that could exact a high societal price, regardless of the size of expected benefits in the new equilibrium.

A standard CGE model assumes that an economy's factors of production are in fixed supply, unless they are changed as a model experiment. For example, the size of the labor force is assumed to be fixed, and the available quantity of capital equipment does not change. Often, models depict a medium-run adjustment period following a model shock. This period is long enough to allow the fixed supplies of factors to change employment in response to changes in wages and capital rents across industries, but it is too short for long-run changes in factor productivity, growth in the size of the labor force, or capital stock accumulation to take place.

We consider both single-country and multi-country CGE models in the following chapters. *Single-country* models describe one country in detail, with a simple treatment of its export and import markets. *Multi-country* CGE models contain two or more countries (or regions) and describe their economies in full, including each country's production, consumption, trade, taxes, tariffs, and so on. The economies in multi-country models are linked to each other through trade and sometimes through capital or labor flows.

No one CGE model has all of the features that we describe in the following chapters. Rather, our intent is to provide you with a solid foundation in CGE modeling basics that will equip you to understand or to work with almost any standard CGE model. Later, you can build on this foundation to learn about and appreciate the ramifications of differences among CGE models and the capabilities of more sophisticated or special-purpose models. We describe some of these more sophisticated models and the frontiers of CGE modeling in text boxes throughout the book, and in our concluding chapter.

CGE Model Structure

A CGE model consists, essentially, of a set of commands. Some of the commands simply provide the model preliminaries. They define sets, parameters, and exogenous and endogenous variables. We discuss these elements of a CGE model in detail in Chapter 2. Other commands present the economic equations of the model. These are typically organized into blocks related to:

- consumption
- production
- factor markets (e.g., capital and labor)
- international trade
- taxation

We explore each of these economic components of a CGE model separately and in depth in Chapters 4 through 9.

CGE Model Database

A CGE model database provides the values of all exogenous variables and parameters, and the initial equilibrium values of all endogenous variables. The database is typically maintained in a computer file separate from the CGE model, which is written in general functional notation. This approach makes it easier for the researcher to use the same general CGE model but swap databases when the country, sectors, or factors under study change. When the model database is read into the general model, the researcher now has a quantitative CGE model that can yield numerical solutions.

A CGE model's database has two components. The first is called a Social Accounting Matrix, or SAM. A SAM describes the circular flow of income and spending in a national economy during a specific time period, usually a year, such as 2007. It reports the values of all goods and services that are produced and the income generated from their sale. It describes households' income and their spending, government tax revenue and outlays, savings and investment spending, and international trade. CGE model databases typically use data from official national accounts. The second component of the CGE model database presents elasticity parameters. Elasticities describe producer and consumer responses to changes in prices and income.

To be tractable, a CGE model database must be aggregated to provide a summary description of all of this economic activity. Industries are therefore aggregated into representative groups of industries, such as agriculture, manufacturing, and services. Households' transactions are often summed into those of a single, representative household, or into a small number of household types, perhaps categorized by income class, geographical location, or demographic characteristics. The goods and services consumed in the economy are also aggregated into broad categories of commodities, such as agriculture, manufacturing, and services.

Every researcher must decide how to aggregate economic activity in his or her database, balancing the need for detail, for example on specific industries that are relevant to the research question, with the benefits that a small, highly aggregated database offers in terms of experimenting with the model, and understanding and communicating model results. Many CGE modelers use the global CGE model database developed by the Global Trade Analysis Project (GTAP) (see Text Box 1.1). Modelers typically aggregate this database in ways that are relevant to their research question. For example, we use the GTAP database to develop a small, three-sector, three-factor database for 2007 for the United States and an aggregated rest-of-world region. The three sectors are agriculture, manufacturing, and services, and

Text Box 1.1. The GTAP Global Database

"Chapter 1: Introduction" (Narayanan and Hertel, 2015).

The Global Trade Analysis Project (GTAP) database, developed and maintained by researchers at Purdue University, is a publicly available resource (www.gtap.org) that provides the core data sets required by CGE models. These data include input-output tables, bilateral trade flows, transport costs, tax and tariff information, and all other data that comprise the Social Accounting Matrices (SAMs) and elasticity parameters used in CGE models. This book, for demonstration, uses Version 8.1 of the GTAP database. Released in 2013, it describes 134 countries or regions and 57 commodities in a 2007 base year. The GTAP global database is regularly updated every three to four years and relies on broad participation by a network of database users who donate data.

the three factors of production are land, labor, and capital. We use this small "U.S. 3×3" model for demonstration throughout this book.

CGE Model Applications

CGE models have been applied to the study of a wide and growing range of economic problems. A comprehensive guide to their applications is well beyond the scope of this book, or indeed of any one survey article. Nevertheless, there are several noteworthy books, articles, and surveys that can provide you with a solid introduction to this growing body of literature. The early CGE model applications were mainly to tax policies in developed countries and to development policy in developing countries. Recommended surveys of this early literature are Shoven and Whalley (1984) and Pereira and Shoven (1988), who survey CGE-based analyses of taxation in developed countries. deMelo (1988) and Bandara (1991) review CGE analyses of trade and development policy in developing countries, and Decaluwe and Martens (1988) provide a survey of CGE-based country studies. These classic surveys remain of interest for new modelers because they served as introductions of CGE models to the economics profession and thus include overviews of the core structure and behavior of CGE models.

By the early 1990s, many CGE modelers began to focus on trade liberalization within regional free trade areas and at the global level. Informative surveys of this literature include Robinson and Thierfelder (2002) and Bouet (2008). A new generation of trade-focused CGE models is now examining non-tariff, regulatory barriers that affect trade in both goods and services. Fugazza and Maur (2008) and Tarr (2013) offer introductions to this innovative area in trade policy modeling.

CGE models also have been applied to the study of subnational regions. Partridge and Rickman (1998) survey approaches to developing regional CGE models that describe economic activity at subnational levels; Giesecke and Madden (2013) provide a more recent review of this class of models. Notable examples of regionalized CGE models are the USAGE-ITC model of the United States, developed by Dixon, Rimmer, and Tsigas (2007), and studies of Morocco (Diao et al., 2008) and of Ethiopia (Block et al., 2006). Also, see Taylor et al. (1999), who developed an interesting CGE model of a village in Mexico.

More recently, CGE models have begun to make important contributions to the analysis of climate change impacts, the costs and benefits of mitigating policies, and the potential for adaptive behaviors. Bergman (1988, 2005) and Bhattacharyya (1996) survey the CGE-based climate change literature, and Burniaux and Truong (2002) detail and compare the approaches to modeling climate change mitigation in several prominent CGE models. Other influential contributions to climate analysis are based on the EPPA Model developed at the Massachusetts Institute of Technology (Paltsev et al., 2005), and CIM-EARTH, a CGE model developed at the University of Chicago and Argonne National Laboratory (Elliott et al., 2010a).

The growing diversity of CGE model applications means that many innovative studies are not readily categorized into the broad areas described in surveys. Some examples that may help you appreciate the breadth of CGE model applications include analyses of the economic effects of AIDS/HIV (Arndt, 2002) and of the Ebola Virus (Bulman et al., 2014), tourism and climate change (Berrittella et al., 2004), growing antibiotic resistance (Keogh et al., 2009), consumer aversion to genetically modified foods (Nielson, Thierfelder, and Robinson, 2001), employment alternatives to illegal gold mining in Peru (Pineiro et al., 2016), investments in regional transportation grids (Sakamoto, 2012), and the modernization of retail food shopping in India (Landes and Burfisher, 2009). As you undertake a literature review for your own research project, you will discover many innovative and creative ways that CGE models are being applied today.

Summary

A CGE model is a system of equations that describes an economy as a whole and the interactions among its parts. Its equations describe producer and consumer behavior and impose market-clearing constraints, and they are solved for the set of prices at which the quantities of supply and demand are in equilibrium in all markets. A model experiment perturbs this equilibrium, and the model is re-solved for new market-clearing prices and quantities. In this book, we study a "standard" CGE model, which is a static (single-period), single- or multi-country model with fixed national supplies of the factors of production (e.g., labor and capital). CGE models have been applied to the study of a wide and growing range of economic problems including taxation, economic development, trade policy, climate change, tourism, transportation, and disease.

Key Terms

Circular flow of income and spending
Computable general equilibrium model
Endogenous variable
Equilibrium
Exogenous variable
Multi-country model
Partial equilibrium model
Single-country model
Static model

PRACTICE AND REVIEW

1. Solve the bicycle model.

   A CGE model is solved to find the set of prices at which quantities supplied are equal to the quantities demanded. In this exercise, you are asked to solve a partial equilibrium model of the bicycle industry for the market-clearing price and quantities.

   Model equations:

$$QD = 2Y - 2P$$

$$QO = -4P_i + 2P$$

$$QO = QD$$

   Exogenous parameters:

$$Y = 6$$

$$P_i = 1$$

   Solve for the base values of the two endogenous variables:

   P____________________________

   QO = QD = ________________

2. Carry out a model experiment.

   Model experiments change the value of an exogenous variable(s) or parameter(s), and the model solves for new values for the model's endogenous variables. Assume that the exogenous variable in the bicycle model, income, Y, has increased from 6 to 8. Solve for the new equilibrium values of the endogenous variables:

   P____________________________

   QO = QD = ________________

3. Partial vs. General Equilibrium Analysis of the Bicycle Industry

   How important is a general equilibrium perspective in economic analysis? Is it possible that conclusions based on a partial equilibrium analysis could be wrong in either magnitude or the direction of change? In this exercise, you are asked to use your economic theory to make predictions about changes in the output price and output level of the bicycle industry following a price shock to one of its inputs – rubber tires. First, you will consider only the effects on supply and demand for bicycles – this is a partial equilibrium analysis that could be drawn from the simple bicycle model we developed in this chapter. Then you will be asked to consider some general equilibrium dimensions of the problem, and to compare these results with the partial equilibrium analysis. You are simply asked to reach

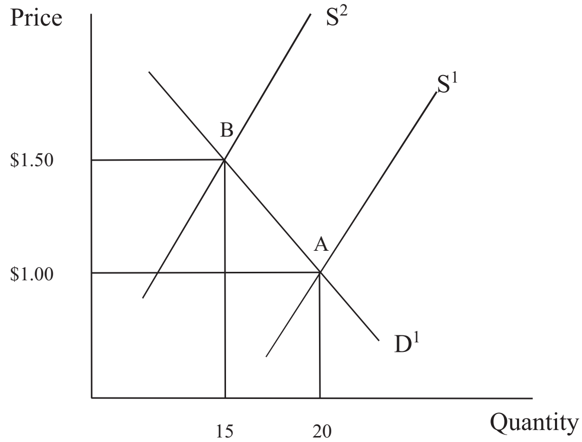


Figure 1.2. Effects of higher rubber tire prices on the domestic bicycle industry.

qualitative conclusions about the general equilibrium impacts of an increase in the price of rubber tires.

Assume that the market is perfectly competitive, so that bicycle producers are price-takers in both input and product markets. This is shown in Figure 1.2, where D^1 is the demand for bicycles and S^1 is the initial supply of bicycles. In the initial equilibrium, at point A, 20 bicycles are supplied and demanded at a price of $1.00 per bike.

Consider the effects of the increase in price of rubber tires on bicycle production and sales price. An increase in input costs shifts the supply upward to S^2, because producers must now charge a higher price for any given quantity of bicycles. (We could also say that the supply curve shifts left, because a smaller quantity can be produced for any given price.) The increase in price causes the quantity demanded to fall, shown as a movement along the demand curve, D^1. At the new equilibrium, at point B, the bicycle price has increased by 50%, to $1.50, and the quantity demanded has fallen by 25%, to 15.

This is a partial equilibrium analysis of the bicycle industry. The results are reported in the first row of Table 1.2. You will use these base results for comparison with your general equilibrium results.

Next, consider the interactions between the bicycle industry and the rest of the economy – a general equilibrium analysis. Analyze each of the following circumstances, *each independent of the rest.* Show how each of these factors individually can lead to an outcome that modifies the result of your partial equilibrium analysis.

Start by describing how each of the following factors causes a shift in either the supply curve, S^2, or the demand curve, D^1, and results in a new equilibrium price and quantity of bicycles. In Table 1.2, compare the new

Table 1.2. *Partial versus General Equilibrium Analysis*

	Bicycle Equilibrium Price Is Higher/ Lower than $1.50	Bicycle Supply/ Demand Equilibrium is Greater/Less than 15	Which Curve Shifts and in Which Direction?
Increase in price of rubber tires	$1.50	15	Supply (S^1)– upward/left
Bicycle workers accept lower wages	higher/lower	greater/less than	
Consumer demand shifts to imported bicycles	higher/lower	greater/less than	
Decline in exports causes depreciation and higher imported input costs	higher/lower	greater/less than	
Bicycle seat price falls due to fall in demand from bicycle producers	higher/lower	greater/less than	

equilibrium with the results reported in the first row of the table, which describe point B. When you are done, look at the entries in the table and consider how your general equilibrium analysis compares with the partial equilibrium results.

In this thought exercise, you consider each of the factors individually. In a CGE model, all of these forces influence model results simultaneously. As you progress through this book and learn how to interpret your CGE model results, you may want to return to this exercise to remind yourself of some of the most important factors that may explain your new equilibrium.

1. Bicycle workers are highly specialized and unable to find work easily in other industries. Because of their limited job mobility, they choose to accept a drastic reduction in their wage to retain their jobs. The wage cut lowers the cost of bicycle production.
2. Imported bicycles are now cheaper than those made in the domestic industry. Because customers find imported bicycles to be almost indistinguishable from domestic ones, the domestic price increase causes the market share of imports to increase relative to domestically produced bicycles. Assume that the demand curve reports only demand for domestically produced bikes.
3. Assume that the higher price of rubber has increased the cost of production of autos, Tupperware, and many other products, causing exports of these goods to fall and the domestic currency to depreciate. Most of the steel used to produce bicycles is imported. How will depreciation influence your input costs and the supply curve for bicycles?

4. Any decline in your bicycle production reduces your demand for all of your inputs. Because you are the only industry that uses bicycle seats, your reduced production causes their price to drop. How will the falling price of your input from this "upstream" industry affect your supply curve, sales price, and output level?

2

Elements of a Computable General Equilibrium Model

In this chapter, we deconstruct the computable general equilibrium model and describe its core elements. These include sets, endogenous and exogenous variables, exogenous parameters, behavioral and identity equations, and model closure. We describe prices, price normalization, price transmission, and the numeraire. We explain how the CGE model runs and how to carry out an experiment.

A computable general equilibrium (CGE) model is a system of mathematical equations that describes an economy as a whole and the interactions among its parts. A model this comprehensive is more complex than the bicycle industry model we built in Chapter 1, but it need not be a "black box." In this chapter, our objective is to introduce, at a general level, the model's elements and mechanics. Even so, for many students, it may suffice to skim this chapter and return to it as needed as your modeling skills progress. For now, we also set aside any consideration of the economic theory that governs behavior in the model. Here, we do not consider how the model describes the motivations behind producers' decisions about how much to produce or consumers' decisions about how much to buy, or a nation's choice between consumption of its domestic production and imported goods. Of course, the economic properties of a CGE model are its real heart and soul, but they also present a much broader area of study; most of the other chapters in this book address this study.

In this chapter, we deconstruct the CGE model to describe its core elements. We show that a CGE model and the simple bicycle model share many features, such as exogenous and endogenous variables, market-clearing constraints, and identity and behavioral equations. We explain and compare linearized and nonlinear expressions of the behavioural equations in a CGE model. We describe how the price of a single good changes as it moves along the supply chain from producers to consumers and the implications for price transmission. We explain the practice of normalizing prices and the role of the price numeraire. We introduce model closure, which is the decision about which variables are exogenous and which are endogenous. We also describe how the CGE model runs by explaining the sequence of model calibration or consistency check, baseline model solution, and model experiment.

Sets

A CGE model starts by introducing sets. *Sets* are the domain over which parameters, variables, and equations are subsequently defined. For example, we can define set *i* as industries, which in the 3×3 U.S. database consists of agriculture, manufacturing, and services. If "QO" is output, then we can define a variable QO_i, which is the output quantity defined over the set *i*. That is, QO_i is a vector with three elements. It includes the output of agriculture, output of manufacturing, and output of services. To refer to only one element in set *i*, for example, the quantity of agricultural output, we express the variable as $QO_{\text{"agriculture"}}$, where one element of set *i*, in this case agriculture, is identified in quotes.

Similarly, we might define a different variable, PS, over the same set *i*, where PS is the producer price. If our equation refers to PS_i, then we are referring to the producer prices of agriculture, manufacturing, and services. To refer to the producer price of services alone, we would identify the set element in quotes, as $PS_{\text{"services"}}$.

Different variables in the CGE model can have different set domains. For example, our model might include a set *f* that contains two factors of production – labor and capital. In that case, we could define variable QF_f as the national supply of factor *f*. The variable is a vector with two elements – labor and capital. Variables may also have more than one domain. For example, variable $QFE_{f,i}$ is the quantity of factor *f* employed in the production of good *i*. The variable is a matrix, with *f* rows and *i* columns.

In multi-country CGE models, set notation related to bilateral trade usually follows the convention that the first country name is the source country and the second country name is the destination country – that is, variable $QMS_{i,r,s}$ describes QMS quantity of commodity *i* imported from country *r* by country *s*. For example, $QMS_{\text{"agriculture", "USA", "ROW"}}$ refers to imports of agriculture from the United States by the rest-of-world region. It is equal to $QXS_{\text{"agriculture", "USA", "ROW"}}$, which is the quantity of agricultural goods exported from the United States to the rest-of-world region.

Endogenous Variables

Endogenous variables have values that are determined as solutions to the equations in the model, similar to the equilibrium price and quantity of bicycles in our simple partial equilibrium model of Chapter 1. Examples of

Text Box 2.1. Math Refresher – Working with Percent Changes

CGE model results are usually reported as the percent change from initial, or base, values. The following are three useful mathematical formulae for working with percent change data:

1. **Percent change in a variable** is the new value minus the base value, divided by the base value, multiplied by 100.

   Example: If the labor supply, L, increases from a base value of 4 million to 4.2 million, then:

   $$\text{Percent increase in L} = (4.2 - 4)/4 = 0.05 * 100 = 5$$

2. **Percent change in the product of two variables** is approximately the sum of their percent changes, when the changes are small.

   Example: GDP = P ∗ Q, where P is the price and Q is the quantity of all goods in the economy. If P increases 4% but Q decreases .05%, then:

   $$\text{Percent change in GDP} = 4 + (-.05) = 3.95$$

3. **Percent change in the quotient of two variables** is approximately the dividend (numerator) minus the divisor (denominator), when the changes are small.

   Example: Per capita GDP is GDP/N, where N is population. If GDP grows 1% and N grows 0.2%, then:

   $$\text{Percent change in per capita GDP} = 1 - 0.2 = 0.8$$

endogenous variables in CGE models are prices and quantities of goods that are produced and consumed, prices and quantities of imports and exports, tax revenue, and aggregate savings.

When describing CGE model results, our notational convention in this book is to describe the level of a variable (e.g., the quantity of a good produced or its price) in uppercase letters and to denote the percent change in a variable in lower case italics. For example:

Variable $QO_{\text{“mfg”}}$ = quantity of manufacturing output

Variable $qo_{\text{“mfg”}}$ = percent change in quantity of manufacturing output

A CGE model usually has the same number of endogenous variables as independent equations. This is a necessary (although not a sufficient) condition to ensure that the model has a unique equilibrium solution.

Exogenous Variables

Exogenous variables have values that are fixed at their initial levels and do not change when the model is solved. For example, if a region's labor supply is assumed to be an exogenous variable, then its labor supply will remain at its initial quantity, both before and after a model experiment.

Model Closure

Modelers decide which variables are exogenous and which are endogenous. These decisions are called *model closure*. An example of a closure decision is the modeler's choice between (1) assuming that the economy's labor supply is exogenous, and an endogenous wage adjusts until national labor supply and demand are equal, or (2) assuming that the economy-wide wage is exogenous, and an endogenous labor supply adjusts until national labor supply and demand are equal.

To illustrate the important concept of model closure, assume that we are studying the effects of a decline in the demand for computers, which causes the computer industry's demand for workers to fall. If we assume the nation's total labor supply is exogenous (i.e., fixed at its initial level), then economy-wide wages will fall until all laid-off computer workers are reemployed in other industries. However, if the closure instead defines the economy-wide wage as exogenous (and fixed at its initial level), then the loss of jobs in the computer industry may cause national unemployment but will have no effect on wages. Because a change in the size of a country's labor force changes the productive capacity of its economy, its real gross domestic product (GDP) will decline more in a CGE model that allows unemployment than in a model whose closure fixes the national labor supply.

Because the choice of closure can affect model results in significant ways, modelers try to choose closures that best describe the economy they are studying. CGE models usually have a section of model code that lists model closure decisions. In the Global Trade Analysis Project (GTAP) model, for example, one of the tabbed windows on the model's front page is titled "Closure." The closure page lists all of the exogenous variables, and the remainder is endogenous.

Exogenous Parameters

CGE models include *exogenous parameters* that, like exogenous variables, have constant values. CGE models contain three types of exogenous parameters: tax and tariff rates, elasticities of supply and demand, and the shift and share coefficients used in supply and demand equations.

Tax and Tariff Rates

Tax and tariff rates are typically calculated by the CGE model from the model's base data. For example, a CGE model database reports the value of imports in world prices and the amount of tariff revenue that is paid to the government. The model calculates the exogenous parameter – the import tariff rate – as:

$$\text{Value of tariff revenue/Value of imports in world prices} * 100 = \text{Import tariff rate}$$

If the tariff revenue is \$10, and the world price of the import (including freight and other trade costs) is \$100, then consumers pay \$110, and the model calculates a tariff rate of 10%.

Modelers can change tax and tariff rates as a model experiment to analyze "what if" scenarios. For instance, the modeler may want to know what would happen in the economy if the government reduces the import tariff rate. As an experiment, the modeler lowers the tariff and re-solves the CGE model to find the resulting prices and the new quantities that are demanded and supplied.

Elasticity Parameters

Elasticities are exogenous parameters in a CGE model that describe the responsiveness of producers and consumers to changes in relative prices and income. The magnitudes of model results stem directly from the size of the elasticities assumed in the model. For example, suppose that the National Chefs' Association has asked you to study the possible effects of economic growth on the demand for restaurant meals. If consumer demand for restaurant meals is assumed to be very responsive to income changes (so the income elasticity of demand parameter is high), then even a small increase in income will lead to a relatively large increase in the demand for restaurant services. However, if the income elasticity is assumed to be low, then even large economic growth will have only a small effect on the quantity of demand for restaurant services. Because the assumed value for the income elasticity of demand determines how much the demand for restaurant meals will increase for any given change in income, the parameter is a critical component of your analysis.

The types of elasticities used in CGE models vary because they depend on the types of production and utility functions assumed in the model. Some elasticities may not be the types that you are familiar with from your microeconomics studies. In the following two sections, we describe the supply and demand elasticity parameters used in many CGE models and show how each influences the slope or shift in supply or demand curves. A standard CGE model generally utilizes some, but not all, of these parameters.

Supply Elasticity Parameters

Factor Substitution Elasticity. This parameter, σ^{VA}, relates to demand for factors of production, for example, labor, L, and capital, K. A producer combines labor, capital, and any other factors into a bundle, called "value added," that is used in the production process. This elasticity describes the flexibility of a production technology to allow changes in the quantity ratios of factors used in a given bundle of value added as relative factor prices change. For example, the parameter describes the ease with which producers in an industry can hire more labor and use less capital when the wage falls relative to the price of machinery and equipment.

The elasticity – one for each industry *i* in the model – describes the percent change in the quantity ratio of factor inputs given a percent change in their inverse price ratio and holding the bundle of factor inputs constant:

$$\sigma_i^{VA} = \frac{\%\ \text{change}\dfrac{L_i}{K_i}}{\%\ \text{change}\dfrac{R_i}{W_i}}$$

where L_i and K_i are labor and capital employed in industry *i*, and R_i and W_i are the industry's capital rent and wage. The parameter's value ranges from zero to infinity. For example, an 0.5% factor substitution elasticity means that a 2% increase in capital rents relative to wages will lead to a 1% increase in the ratio of labor to capital quantities in the production process. As the parameter value approaches infinity, labor and capital become perfect substitutes. One worker can always be substituted for the same amount of capital with no reduction in the total quantity of factor inputs. When the parameter is zero, the factors are complements, and producers must use a fixed ratio of capital and labor, regardless of changes in wages compared to rents.

Producers who can more readily substitute among factors have a more elastic industry supply curve, such as curve S^1 in Figure 2.1, where the axes represent output quantity and output price. When this industry increases its output, producers can keep the costs of production low by switching to lower cost factor inputs. For example, an industry with a flexible technology (a high factor substitution elasticity) can become more mechanized if its expansion causes wages to increase by more than capital rents. An industry with a more rigid technology and a low factor substitution elasticity is described in Figure 2.1 by the less elastic, and steeper, supply curve, S^2.

Intermediate Input Substitution Elasticity. This parameter, σ^{INT}, is analogous to the factor substitution elasticity except that it describes the demand for intermediate inputs, such as tires and steering wheels used in the

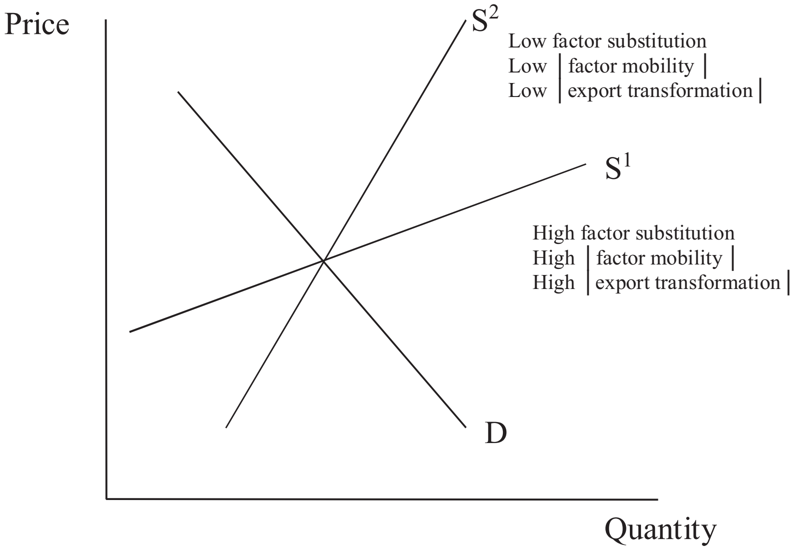


Figure 2.1. Effects of supply elasticity parameters on the slope of the supply curve.

production of a car. The producer assembles these inputs into a bundle of intermediate inputs. This bundle is then combined with the bundle of factor inputs to produce a final product.

The elasticity – one for each industry *i* in the model – describes the percent change in the quantity ratio of two intermediate inputs, Q_x and Q_y, given a percent change in their inverse price ratio and holding the bundle of intermediate inputs constant:

$$\sigma_i^{INT} = \frac{\%\ \text{change} \dfrac{Q_x}{Q_y}}{\%\ \text{change} \dfrac{P_y}{P_x}}$$

where P_x and P_y are the prices of the two intermediate inputs. The parameter's value can range from zero to infinity. In most standard CGE models, the parameter value is assumed to be zero. Intermediate inputs are described as "Leontief" complements that must be used in fixed proportions to produce the final good. For example, production of every car requires four tires and one steering wheel. No substitution between these inputs is possible regardless of any changes in their relative prices.

Aggregate Input Substitution Elasticity. Once the bundle of value added (QVA) and the bundle of intermediate inputs (QINT) in industry *i* are assembled, this parameter, σ^{AGG}, describes the flexibility allowed by the production technology to vary the quantity ratios of the two bundles in the production of the final good. The elasticity – one for each industry *i* in the model –

describes the percent change in the quantity ratio of the valued added and intermediate bundles given a percent change in their inverse price ratio and holding total output of the final good constant:

$$\sigma_i^{AGG} = \frac{\%\text{ change}\dfrac{QVA_i}{QINT_i}}{\%\text{ change}\dfrac{PINT_i}{PVA_i}}$$

where $PINT_i$ is the price of the intermediate input bundle and PVA_i is the price of the value added bundle. The parameter's value can range from zero to infinity. In most standard CGE models, the parameter value is assumed to be zero. The two bundles are "Leontief" complements that must be used in fixed proportions to produce the final output, regardless of any changes in their relative prices.

Factor Mobility Elasticity. This elasticity parameter, σ^F, relates to factor supply. It describes the ease with which a factor moves across industries in response to changing industry wages or rents, for a given national supply of a factor. For example, it describes the willingness of a worker to move to another industry if it offers higher wages than his current job.

One elasticity is defined for each factor *f* in the CGE model. It governs the percent change in the share of the national factor supply employed in industry *i* given a percent change in the economy-wide average factor price relative to the wage or rent paid by an industry. For example, the labor mobility elasticity describes the change in industry *i*'s employment (L_i) relative to the total labor force, L, as a function of its wage (W_i) relative to the economy-wide wage, W:

$$\sigma^F_{\text{“labor”}} = \frac{\%\text{ change }\dfrac{L_i}{L}}{\%\text{ change }\dfrac{W}{W_i}}$$

The parameter value can range between zero (factors cannot move between sectors) and negative one (factors move proportionately to a change in relative factor prices). The lower range restriction of negative one reflects that the factor supply function, in those CGE models that explicitly include one, is used to describe relatively inflexible factor movements. As an example, an elasticity of –0.5% means that a 2% increase in the wage in the computer industry relative to the average wage results in a 1% increase in the share of the labor force employed in computers.

When an industry employs factors that move sluggishly (with low absolute values of the mobility elasticity), its supply curve becomes relatively steep, like S^2 in Figure 2.1, where the axes represent output quantity and output price. This is because its wage and rental costs must rise sharply to attract the additional factors needed to increase production. The more mobile factors are and the larger the parameter's absolute value, the more elastic is the industry's supply curve, such as S^1 in Figure 2.1.

Export Transformation Elasticity. This parameter, σ^E, relates to an industry's export supply. It describes the technological ability of an industry to transform a given level of output between the varieties sold in the domestic and export markets. For example, it describes how easily automakers could shift production between models for the home market and models that are more popular in foreign markets.

For each industry *i*, the elasticity measures the percent change in the ratio of the export quantity, QE, to the quantity sold domestically, QD, given a percent change in the ratio of the producer's domestic sales price, PDS to its world export price, PWE:

$$\sigma_i^E = \frac{\%\ \text{change}\dfrac{QE_i}{QD_i}}{\%\ \text{change}\dfrac{PDS_i}{PWE_i}}$$

One export transformation elasticity is defined for each industry, with a value that ranges from zero to negative infinity. For example, a –0.8% parameter value means that a 2% increase in the domestic price relative to the export price will lead to a 1.6% decline in the quantity ratio of exports to domestic sales in producers' total output.

If the parameter has a low absolute value, then the resources used in the production of one variety are relatively difficult to transform into the production of the other variety. For example, to increase their production of exports, producers must shift toward greater use of relatively unsuitable inputs taken from the production of the domestic variety. This raises the cost of expanding export sales and therefore limits the export supply response. In Figure 2.1, assuming that the axes represent export quantity and export price, the lower the absolute value of the export transformation elasticity, the less elastic (and steeper) the industry's export supply curve such as S^2 in Figure 2.1. When the export transformation parameter is high in absolute value, then producers can readily expand their export output with less upward push on their costs of production. Their export supply curve is therefore more elastic, such as S^1.

Demand Elasticity Parameters

Income Elasticity of Demand. This elasticity parameter (η) describes the effect of a change in income on demand for a commodity. One parameter is defined for each consumption good *i* in the model. It measures the percent change in the quantity demanded, Q_i, given a percent change in income, Y:

$$\eta_i = \frac{\%\ \text{change}\ Q_i}{\%\ \text{change}\ Y}$$

Income elasticity parameter values between zero and less than one indicate *necessity goods*, such as food, for which demand grows by proportionately less than growth in income. Parameter values greater than one describe *luxury goods*, for which demand grows by proportionately more than growth in income. An income elasticity of one describes consumers whose quantity demanded changes by the same proportion as their income.

In CGE models, goods are usually "*normal*"; that is, income elasticities are positive so that an increase in income leads to an increase in demand for a good. Not all CGE models allow the modeler to specify an income elasticity of demand. Often, the models assume utility functions in which the income elasticity of demand is "hardwired" to have a value of one. See Chapter 4 for a more complete discussion of this point. In Figure 2.2, a change in income could be shown as a shift in the demand curve, where the axes represent the quantity of the commodity and its consumer price. The higher the income elasticity, the larger the rightward (leftward) shift in the demand curve for any given increase (decrease) in income.

Own-Price Elasticity. This parameter measures the responsiveness of consumer demand to changes in the price of commodities. The own-price

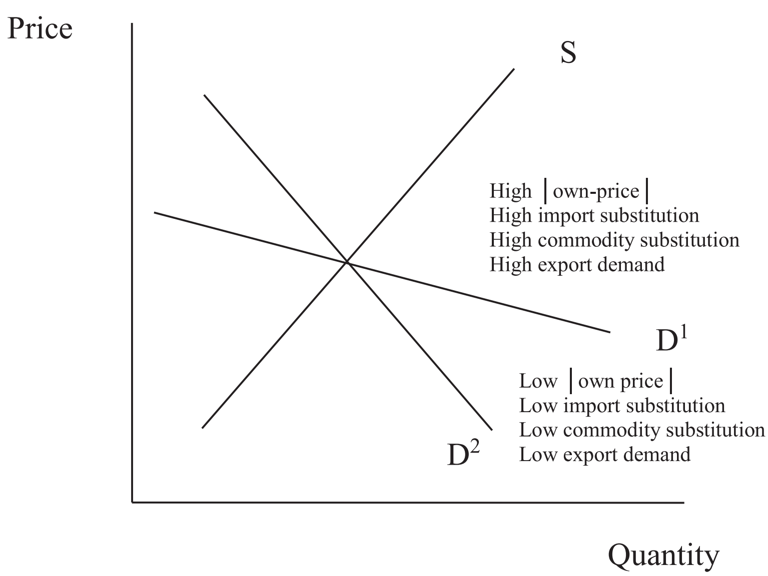


Figure 2.2. Effects of demand elasticity parameters on the slope of the demand curve.

18:27:44,
.003

elasticity (ε_i) measures the percent change in quantity demanded for good *i* given a percent change in its consumer price, P_i:

$$\varepsilon_i = \frac{\%\ \text{change}\ Q_i}{\%\ \text{change}\ P_i}$$

CGE models generally assume that the *Law of Demand* holds; that is, an increase in the price of a good causes the quantity demanded to fall, so the own-price elasticity of demand is negative. When consumer demand is price sensitive, the own-price parameter is large in absolute terms. In this case, the demand curve for good is relatively elastic, such as curve D^1 in Figure 2.2, where the axes describe the quantity demanded of good *i* and its consumer price. When the own-price elasticity parameter is low, then the demand curve becomes less elastic, such as D^2.

Commodity Substitution in Consumer Demand Elasticity. This parameter, σ^C, describes the willingness of consumers to substitute among the goods in their consumption basket, at a given level of utility, when the relative prices of the commodities in that basket change. In a two-good example, the parameter measures the percent change in the quantity ratio of commodity Q_i relative to commodity Q_j given a percent change in the inverse of their price ratio:

$$\sigma^C_{i,j} = \frac{\%\ \text{change}\dfrac{Q_i}{Q_j}}{\%\ \text{change}\dfrac{P_j}{P_i}}$$

An increase in price P_j, the price of commodity *j*, relative to P_i, the price of commodity *i*, will cause the quantity demanded of *j* to decrease and the quantity demanded of *i* to increase, and vice versa. A parameter value that is near infinity describes two goods that are strong *substitutes* (like brown sugar and dark brown sugar). A value that approaches zero describes two goods that are *complements* (like left shoes and right shoes). In Figure 2.2, a high value for the parameter is represented by a more elastic demand curve, such as D^1, for good *i*. As the parameter value becomes smaller, the demand curve becomes more inelastic, as described by demand curve D^2.

Import-Domestic Substitution (Armington) Elasticity. This parameter, σ^D, relates to consumer demand for imports. It describes consumers' willingness to shift between quantities of imported (QM) and domestically produced varieties (QD) in their consumption of a given quantity of commodity *i* as the relative price of domestic (PD) to imported (PM) varieties changes. For example, it describes a consumer's willingness to shift from an imported car to a domestic model when the relative price of the import rises.

The parameter is calculated as the percent change in the quantity ratio of imports to the domestic variety given a percent change in their inverse price ratio:

$$\sigma_i^D = \frac{\%\ \text{change}\dfrac{QM_i}{QD_i}}{\%\ \text{change}\dfrac{PD_i}{PM_i}}$$

Its value may range between zero and infinity. For example, if the substitution elasticity is 2, then a 1% increase in the price of the domestic relative to the imported variety will lead to a 2% increase in the ratio of the import relative to the domestic quantity for a given utility level. Assume that the axes in Figure 2.2 describe quantities of imports and the import price. When the import-domestic substitution parameter has a low value, import demand is inelastic, shown as D^2 in Figure 2.2. As the parameter value increases, the import demand curve becomes more elastic, such as D^1.

Import-Import Substitution (Armington) Elasticity. Some CGE models have a second import demand elasticity, σ^M, that describes consumers' willingness to shift among foreign sources of imports. The parameter is analogous to the import-domestic elasticity of substitution. It defines the consumer's willingness to shift its quantity of imports from country j (QMS_j) to country k (QMS_k) for a given level of imports, as the price of the import from country j (PMS_j) changes relative to that of country $k (PMS_k)$.

The parameter is calculated as the percent change in the quantity ratio given a percent change in their inverse price ratio:

$$\sigma_i^M = \frac{\%\ \text{change}\dfrac{QMS_k}{QMS_j}}{\%\ \text{change}\dfrac{PMS_j}{PMS_k}}$$

The parameter's value may range between zero and infinity. Assume that the axes in in Figure 2.2 represent the quantity of imports from country j and the price of imports from country j. When the import-import substitution parameter has a low value, the demand for imports from country j is inelastic, shown as D^2 in Figure 2.2. As the parameter value increases, the import demand curve becomes more elastic, such as D^1.

Export Demand Elasticity. Single-country CGE models describe the rest of the world's demand for a country's exports as a function of its export price. Usually, when its export price rises relative to the world price, the country's foreign sales will fall. An export demand elasticity parameter, θ, is defined for each exported commodity i in the CGE model. It describes the percent change in the share of a country's exports, QE, in world trade, QW, given a percent change in the ratio between the average world price, PXW, and the exporter's price, PWE:

$$\theta_i = \frac{\%\text{ change}\dfrac{QE_i}{QW_i}}{\%\text{ change}\dfrac{PXW_i}{PWE_i}}$$

An increase in the exporter's price relative to the world price causes its export quantity and world market share to decline. The larger the elasticity parameter value, the larger the decline in its exports as the country's relative export price increases. The export demand elasticity ranges from zero to infinity. A parameter value that approaches infinity describes a small country in world markets, so even a small deviation in its export price relative to the world price will result in a large change in its market share. A parameter value near zero describes a very large country in world markets. In Figure 2.2, if we assume that the axes represent the quantity of a country's export good and its export price, then a high value of the export demand elasticity parameter is shown as the very elastic export demand curve, D^1, for a small country's exports. A low parameter value is described by the relatively inelastic export demand curve of a large country, D^2.

Shift and Share Parameters

Shift parameters and *share parameters* are exogenous values used in the supply and demand equations in a CGE model. As an example, consider the shift and share parameters in a Cobb-Douglas production function. This function is used in some CGE models to describe the production technology of an industry:

$$QO = A(K^{\alpha}L^{1-\alpha})$$

where QO is the output quantity. Parameter A is a shift parameter whose value is greater than zero and that describes the productivity of capital, K, and labor, L, in the production process. Parameter α is a share parameter, ranging between zero and one. It measures the share of K in the total income received by labor and capital from their employment in the industry. Labor's income share parameter is $1 - \alpha$.

Parameter A is called a shift parameter because a change in its value causes the industry supply curve to shift to the right or the left. For example, if the shift parameter increases in value, perhaps from $A = 5$ to $A = 10$, then factors are more productive, and the same quantity of K and L can produce a larger quantity of output. This change in the shift parameter is described by the rightward shift in the supply curve from S^1 to S^2 in Figure 2.3. CGE modelers

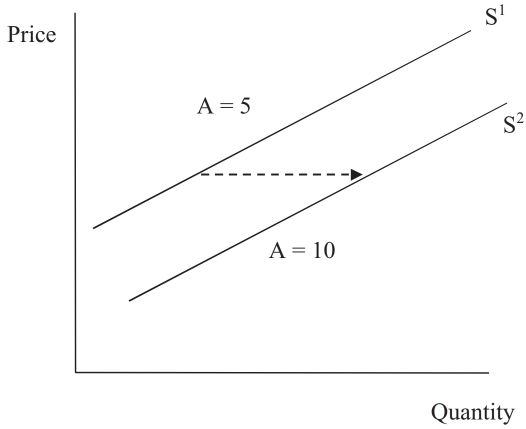


Figure 2.3. Effect of an increase in the shift parameter value on the supply curve.

can change the value of the shift parameter in the production function as a model experiment to describe changes in factor productivity.

Share parameters used in production and consumption equations in a CGE model describe percentage shares that are calculated from the base data. Some examples are shares of each commodity in consumers' total consumption, shares of imported and domestic varieties in the demand for commodities, and shares of domestic and export sales in total industry output.

Equations

CGE models have behavioral and identity equations. *Behavioral equations* describe the economic behavior of producers, consumers, and other agents in the model based on microeconomic theory. You may recognize some of the behavioral supply-and-demand equations in the model from your economics coursework. For example, CGE models include a behavioral equation that describes how firms minimize the costs of inputs to produce a specific level of output, given input and output prices and subject to the technological constraints of their production process.

CGE models also include a utility function that describes the combinations of goods that consumers prefer. The choice of utility function – for example, Cobb-Douglas or Stone-Geary – depends on which best describes consumer preferences in the country under study. Given consumers' preferences, a behavioral equation describes how they choose quantities of goods that maximize their utility subject to the prices of goods and their budget. Additional behavioral equations in the CGE model explain the demand for imports and the supply of exports.

Identity equations define a variable as a mathematical function (sum, product, etc.) of other variables. Identity equations therefore hold true by definition. If the value of any one of the variables in the identity equation changes, then one or more of the other variables must also change in order to maintain the equivalence.

Some identities are accounting equations. For example, they ensure that the consumer retail price is the sum of the wholesale price plus the retail sales tax. Other identity equations act as constraints in a CGE model to ensure that the model solves for a market-clearing set of prices at which quantities supplied and demanded are equal. These equations are similar to the market-clearing constraint in our bicycle model of Chapter 1, that QO = QD. Model closure is the choice made by the modeler as to which variable adjusts to maintain a market-clearing identity.

An example of a market-clearing identity equation in a CGE model is this expression:

$$\mathrm{QF_f} = \sum\nolimits_{\mathrm{i}} \mathrm{QFE_{f,i}}$$

The equation states that the total supply (QF) of factor *f* is equal to the sum of industries' demands for factor f ($\mathrm{QFE_{f,i}}$). This identity may impose a full-employment constraint in which a fixed, aggregate supply must equal aggregate demand for each factor *f*.

Macroclosure

CGE models include an identity equation that imposes the constraint that total savings is equal to total investment. Some multi-country models impose this constraint at the global level. Other single and multi-country models impose it at the national level. *Macroclosure* describes the modeler's decision about which of the two macroeconomic variables – savings or investment – will adjust to maintain the identity that savings equals investment.

Standard, static CGE models rely on an identity equation to model savings and investment because these behaviors are determined largely by macroeconomic forces, such as monetary policy and expectations about future economic conditions, that are outside the scope of a real CGE model.[1] Nevertheless, the models must account for them because savings and investment are part of the circular flow of income and spending, with effects on the real economy. Savings affect the demand side of the economy because households and the government allocate some share of their disposable income to

[1] For a more detailed discussion of macroclosure and savings and investment, see Lofgren et al. (2002), Hertel and Tsigas (1997), Robinson (1991), and Dewatripont and Michel (1987). Shoven and Whalley (1984) discuss the effect of the choice of closure in predetermining model results.

savings, which reduces the income they have available for purchases of goods and services. Investment affects the production side of the economy because investors buy capital equipment that is produced by industries.

CGE models differ in their default assumptions as to whether savings or investment adjusts to maintain the savings-investment identity. In some models, such as the default closure in the GTAP model, the savings rate (the percentage of income that is saved) is assumed to be exogenous and constant, so the quantity of savings changes whenever income changes. Investment spending then changes to accommodate the change in supply of savings. A model with this closure is called savings-driven, because changes in savings drive changes in investment. An advantage of this closure is that a nation's savings rate remains the same as the rate observed in the base year. This is appealing if we think that base year savings rates reveal the subjective preferences of a country's households and government.

In other CGE models, aggregate investment is fixed at its initial level, and savings rates are assumed to adjust until savings are equal to investment spending. A model with this closure is called investment-driven. This closure is well suited for the study of countries in which governments use policies that influence savings rates to achieve targeted investment levels.

To demonstrate how this macroclosure decision can matter, assume that a country's income increases. In a savings-driven model, households save a fixed share of their income, so income growth will cause savings to increase and therefore investment spending to rise. In an investment-driven model, investment is fixed, so the supply of savings is also fixed. In this case, households will spend, rather than save, their additional income and their savings rate will fall. Because households and investors are likely to prefer different types of goods, the two alternative closures will lead to a different commodity composition of demand. The savings-driven model is likely to result in an increase in demand for and production of machinery and equipment, which is what investors prefer to buy. An investment-driven model is likely to result in an increased demand for and production of consumer goods, like groceries, apparel, and consumer electronics.

Some CGE models, such as those in the Dervis, deMelo, and Robinson (1982) tradition, specify additional macroclosure rules to describe the current account balance and the government fiscal balance. These macroclosure decisions address components of national savings. The current account closure describes whether foreign savings inflows (the current account) are exogenous and the exchange rate is endogenous, or vice versa. An exogenous current account closure fixes the supply of foreign savings (the current account deficit or surplus) at its initial level and the exchange rate adjusts to maintain it, whereas a fixed exchange rate makes foreign savings endogenous. The government budget closure describes whether government savings

Text Box 2.2. Macroclosure and Structural Adjustment in Costa Rica

"Costa Rica Trade Liberalization, Fiscal Imbalances, and Macroeconomic Policy: A Computable General Equilibrium Model" (Cattaneo, Hinojosa-Ojeda, and Robinson, 1999).

What is the research question? In the 1980s, Costa Rica signed structural adjustment agreements with the World Bank that included trade liberalization, elimination of producer and consumer subsidies, and other policy reforms. How might the broader reform program that Costa Rica must carry out temper the gains from the trade liberalization component?

What is the CGE model innovation? The authors develop a multihousehold SAM for Costa Rica for 1991. Using the IFPRI standard CGE model, they vary macroclosure rules to describe alternative ways to implement structural adjustment commitments.

What is the experiment? A single trade liberalization experiment that removes all import tariffs and export taxes is carried out under two alternative foreign savings closures: fixed foreign savings and an endogenous exchange rate versus a fixed exchange rate and endogenous foreign savings. Both scenarios are also conducted with three alternative closures for government savings: loss of trade tax revenue causes the government to run a deficit; and the government budget balance is fixed with trade tax revenue replaced by a corporate income tax or by a retail sales tax.

What are the key findings? Trade liberalization generates efficiency gains for the economy as a whole, and changes in the distribution of income across households are small. However, there are trade-offs that the government must face to maximize these potential gains. The scenarios offer a blueprint for government policy, recommending reduced government expenditures and higher retail sales taxes to offset the significant loss of trade tax revenues.

(the federal deficit) is endogenous and government spending is fixed, or vice versa.

Modelers choose macroclosure rules that best describe the economy under study. The rules also offer researchers the flexibility to explore macroeconomic policy shocks in a CGE model, such as currency devaluation or pay-go federal budget rules. See, for example, Cattaneo, Hinojosa-Ojeda, and Robinson's (1999) methodical study of the effects of alternative macroeconomic policies in Costa Rica, which are simulated by running the same policy shock with different macroeconomic closures (Text Box 2.2).

Nonlinear and Linearized CGE Models

CGE models generally include a mix of linear and nonlinear equations. Identity equations are typically linear equations. Many behavioral equations are nonlinear. An example is this nonlinear behavioral equation describing consumer demand for imported and domestically produced varieties of a commodity:

$$\frac{QM}{QD} = \alpha \left(\frac{PD}{PM} \right)^{\sigma}.$$

where QM is the quantity demanded of the import, QD is the quantity demanded of the domestically produced variety, α is a constant, PD is the price of the domestic product, PM is the price of the import and σ is the import-domestic substitution elasticity that describes the willingness of a consumer to substitute toward the import as its price falls relative to that of the domestic variety. The variables in this nonlinear equation are expressed in levels. That is, QM is the number of imported items that the consumer demands, QD is the number of domestic items, and PD and PM are the prices per unit price of the domestic and imported varieties, respectively.

Some CGE models are written as systems of linearized equations. In this approach, the nonlinear behavioral equations of the model are expressed in percentage change terms. For example, the nonlinear consumer import demand equation given earlier can be expressed in its linearized form as:

$$qm - qd = \sigma(pd - pm)$$

where *qm* is the percentage change in the quantity demanded for imports of good *i*, *qd* is the percentage change in the quantity demanded for the domestic variety, and *pd* and *pm* are the percentage changes in prices of the domestic and imported varieties. Recall our convention that uppercase letters denote the level of a variable and lowercase letters denote its percentage change.

The two different ways to express CGE model equations are a result of the different solution algorithms used by two of the main CGE modeling softwares. GAMS, a software package used by models including GLOBE, finds solution values for nonlinear equations whose variables are expressed in levels. GEMPACK, the software package used by the GTAP model, solves linearized equations. It traces a nonlinear solution by breaking up the model shock into several smaller shocks and solving sequentially for many small, straight-line segments. After each shock, the levels data are updated and the next small shock is applied until the full shock is implemented. The most important thing to know is that nonlinear and linearized expressions are equally valid ways to describe the same consumer and producer behavior and both solution methods lead to similarly accurate results.[2]

[2] The equivalent accuracy of results was an important question for the CGE modeling community in the early 1990s. Horridge and Pearson (2011) and Horridge et al. (2013) provide an overview and

For most modelers, the decision on how to express the nonlinear equations in their model is mainly a question of convenience. Foremost, they follow the convention used by the CGE model and software that they adopt for their research. Some researchers prefer models in which equations can be expressed in nonlinear form because they can be drawn directly from economic theory and may be easier to add or modify in a model.

Other researchers prefer models with linearized equations. An advantage of this approach is that it avoids the need for model calibration, described in the following section. Also, model results are more intuitive to interpret. Consider, for example, the linearized equation from above that describes import demand. Assume that the substitution elasticity is 1.5 and that the model solution is as follows:

$$5 - 2 = 1.5(3 - 1)$$

You can see straightaway that the larger impact on the quantity ratio of imported to domestic varieties is the 3 percent change in the domestic price, compared to the smaller change in price of the import variety. You can also view the role of the import substitution elasticity in determining this result.

Model Calibration

The model *calibration* procedure, required for a CGE model that is expressed in levels, calculates quantities and prices, and the shift and share parameters used in its production and utility functions so that solutions to the equations replicate the initial equilibrium database. The calibrated model solution is then used as the benchmark equilibrium, against which the results of model experiments are compared. The inputs to the calibration process are the SAM, the model's behavioral equations (such as a Cobb-Douglas production function), and the elasticity parameters.

As an example of the calibration procedure, let's again consider a CGE model that assumes this Cobb-Douglas production function:[3]

$$QO = A(K^{\alpha}L^{1-\alpha})$$

comparison of the history and evolution of CGE modeling software and a comparison of their solution methods. Hertel et al. (1991a) demonstrate that the two expressions of behavioral equations in a CGE model are equally valid starting points for a model solution of the same accuracy. Harrison et al. (1993) also address the equivalent accuracy of results.

[3] Note that the modeler does not need to specify any elasticities in the case of a Cobb-Douglas production function because these are implied by the properties of the function: the own-price elasticity of demand for each factor is –1, and the factor substitution elasticities are 1.

Suppose the SAM reports that the industry employs \$30 worth of capital, K, and \$70 worth of labor, L, with a value of output of \$109. The model calibration process defines these values as quantities by "normalizing" wages, rents and output prices as \$1, so that the quantities of K and L per dollar are 30 and 70, respectively, and the base year quantity of output, QO, is 109 units. The calibration then calculates the share parameters α and $1 - \alpha$. The share of capital, α, in total factor payments of \$100 is 0.3, and the income share of labor, $1 - \alpha$, is 0.7. With these share parameters, and the values of QO, K, and L, the calibration process then solves for A:

$$109 = A(30^{.3}\,70^{.7})$$

whose value is 2. You can also verify for yourself that the production function, with these calibrated shift and share parameters, reproduces the base year output of 109.

The calibrated shift and share parameters used in the model's production and utility functions always remain at their initial values, even though actual shares may later change as the result of model experiments. Modelers sometimes change the calibrated shift parameters used in production functions as an experiment, to analyze the effects of productivity shocks. Sometimes, too, modelers change calibrated share parameters as an experiment. Two interesting examples of this share-parameter approach are Kuiper and van Tongeren (2006), summarized in Text Box 2.3, who change the import share parameters; and Nielson, Thierfelder, and Robinson (2001), summarized in Text Box 4.1, who change consumer budget share parameters.

A linearized model such as GTAP need not be calibrated because its equations are expressed in percentage change terms. It does not require initial levels such as K, L, QO or A. Instead, a linearized model undergoes a consistency check to ensure that solutions to its equations produce a balanced database. This approach saves computing time, once an important consideration.

Normalizing Prices

The value of output of good X is the product of its price times its quantity. For example, the value of production of apples is the product of their price (say, \$1.50 each) and the quantity of apples (10), which is \$15. The database of most CGE models comprises only value flows. It reports the value of output of each good in the model, but not their quantities or prices. It reports the value of factor inputs, such as total labor costs, but not the number of workers who are employed or their wage rates. However, you will see that a CGE model reports the results of model experiments for both quantities and prices. For example, a new production subsidy may increase the quantity of X that is

Text Box 2.3. The Small Share Problem and the Armington Import Aggregation Function

"An Empirical Approach to the Small Initial Trade Share Problem in General Equilibrium Models" (Kuiper and van Tongeren 2006).

What is the research question? CGE-based analyses of trade liberalization describe the effects of eliminating trade barriers on import quantities. The majority of these analyses assume an Armington import aggregation function. The "small share problem" is due to the scaling effect of the share parameter α in the Armington import demand equation:

$$\frac{M}{Q} = \alpha \frac{P_M^{-\rho}}{P_Q}$$

where M is the import, Q is the composite commodity (the sum of imported and domestically produced varieties), P_M and P_Q are the prices of the import and of the composite commodity, respectively, and parameter ρ is related to the import substitution elasticity parameter. Parameter α is the initial quantity share of imports in the consumption of commodity Q. Its value is calculated during model calibration and does not change following a model experiment. Notice that if the initial import share is small, then even a large change in the relative price of the import, or a large increase in the size of the import substitution parameter, can result only in small changes in the import share of consumption. This scaling effect may lead to unrealistically small import quantity results in trade liberalization simulations that cause the import price to fall. Could a gravity model provide an empirical basis for changing the share parameters as part of trade liberalization experiment?

What is the model innovation? The researchers develop a gravity model to identify the role of trade barriers in bilateral trade flows. They use the gravity model to simulate trade liberalization and estimate changes in bilateral trade shares. Then, they modify their GTAP model to adjust the calibrated trade shares to those of the gravity model results as part of a trade liberalization experiment.

What is the model experiment? The authors eliminate global import tariffs and export subsidies (1) with and (2) without changes in import share parameters.

What are the key findings? The adjustments shift bilateral trade flows, causing some regions to gain larger shares of the world market following trade reform and other regions to lose market share, compared to a standard CGE model analysis. Adjusting the import share parameters does not change the size of global welfare effects by very much.

produced by 5% but cause its price to fall by 2%. How does a CGE model develop price and quantity data if its database contains only value data?

CGE models translate value data into price and quantity data by *normalizing* prices. This procedure converts most of the initial, or base, prices

Table 2.1. *Normalizing the Price and Quantity of Apples in a CGE Model*

	Base Values for Apples			50% Increase in Apple Quantity		
	Price	Quantity	Value	Price	Quantity	Value
Actual market data	.5	6	3	.5	9	4.5
Normalized data	1	3	3	1	4.5	4.5

in the model into \$1 or one unit of the currency used in the model.[4] Quantities of goods and of factors of production (e.g., labor and capital) are then interpreted as the quantity per \$1 or unit of currency.

Let's use a simple example of apples to show how prices are normalized. According to the actual market data reported in Table 2.1, apples cost 50 cents each and the initial quantity demanded is 6, so the value of apples sold in the market is \$3. In a CGE model database, we know only the value of apples sales, which is \$3. By normalizing prices, we describe the apple price as \$1 and the quantity as the unit quantity per dollar, which is three. That is, each quantity unit of apples in the model is two actual apples.

Normalizing prices does not affect our results. To illustrate this point, consider what happens if the sales quantity of apples increases by 50%. If we use actual market data, then the value of sales increases to \$4.50 (9 apples $\times$ 50 cents). When we use the normalized data, we get the same answer. The apple quantity rises 50%, from 3 to 4.5 units of apples, and 4.5 apples $\times$ \$1 = \$4.50.

The practice of normalizing data considerably reduces the information needed to build a CGE model database without losing the capability of the CGE model to generate results for prices, quantities, and values. This approach also means that most, but not all, prices in a CGE model have an initial level value of one. Some prices in the CGE model are adjusted to include taxes or subsidies, and these initial prices do not equal one. An example is the domestic price of an import. If its normalized world import price is \$1 and the import tariff is 10%, then the initial domestic price of the imports in the CGE model is \$1.10.

Price Linkages

If you purchase a shirt in China for \$14 that is imported from Brazil, you probably realize that the Brazilian company that manufactured the shirt does not receive \$14 for it. The difference between the price that you pay in China

4 This practice is attributed to Arnold Harberger (1964), who normalized the prices and quantities of factors in a general equilibrium analysis of the U.S. income tax.

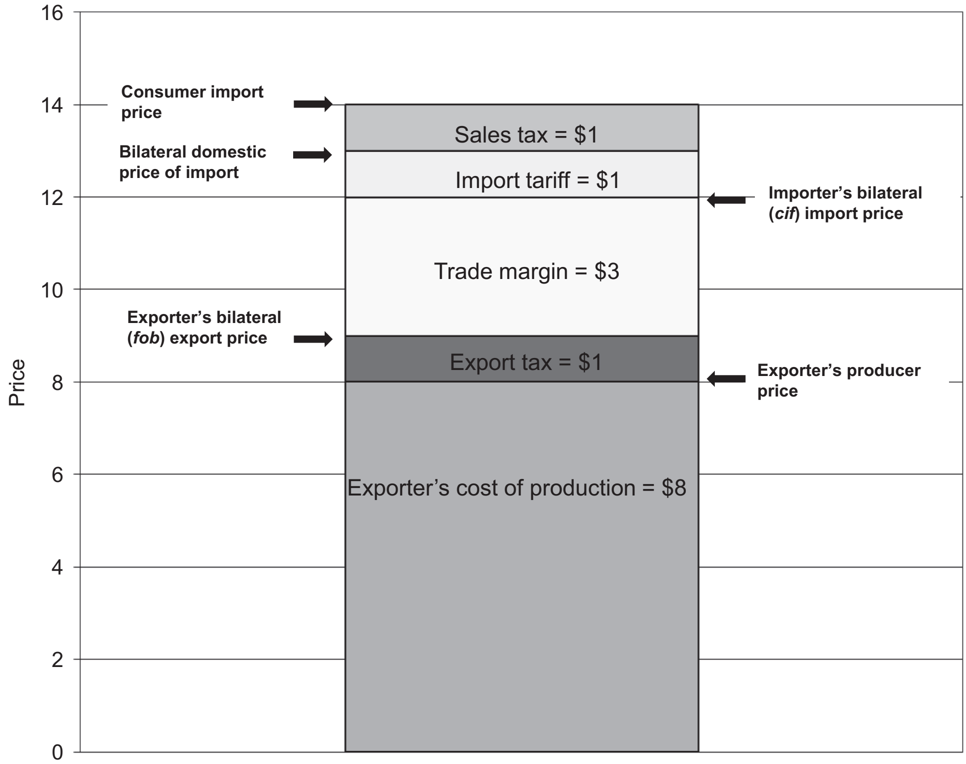


Figure 2.4. Price linkages for a shirt exported from Brazil to China.

and that received by the producer includes any export taxes that the Brazilian firm paid to its government, the cost of transporting the shirt between Brazil and China, and any import tariffs and sales taxes that you paid to your own (Chinese) government. We omit the discussion of the costs of wholesale and retail services incurred in bringing the shirt from the port to your department store.

A CGE model reports several prices for a single commodity, such as this Brazilian shirt, because it tracks goods and prices all along the supply chain from producers to consumers.[5] The *producer price*, $PS_{i,r}$, is the supply price for good *i* received by producers in the exporting country, *r*. In a competitive market it is equal to the cost of production, inclusive of any taxes or subsidies entailed in the production process. The Brazilian shirt, for example, costs $8 to manufacture, so the Brazilian producer price is $8 (Figure 2.4). Brazil's *bilateral fob export price*, $PFOB_{i,r,s}$, is a "free on board" price of its shipments to China, the importing country *s*. An *fob* price is the price of the export good when placed on board the ship at the Brazilian port of departure. It is the producer price plus any export taxes or subsidies on its sales to China.

[5] Appendix B provides a complete list of the prices and quantities in a standard CGE model.

It is described as bilateral because it includes the export tax that is applied to the China market; Brazil may levy different tax rates on exports to its other trade partners. In Figure 2.4, the Brazilian producer pays $1 per shirt in export taxes on sales to China, so its bilateral *fob* export price is $9 per shirt.

Imports incur insurance and freight charges, also called trade margin costs, to move goods from the exporter's port to that of the importer. Like bilateral export taxes, these costs also may differ by partner, depending on distance and other factors. Suppose that the trade margin cost for shipping the shirt to China totals $3. China's *bilateral cif import price*, $\mathrm{PCIF}_{i,r,s}$, for a shirt from Brazil is therefore $12. A *cif* price is the import's cost (its *fob* value) plus insurance and freight charges. China also levies a bilateral import tariff on shirts from Brazil; similar to export taxes, tariffs may vary by trade partner. The *bilateral domestic price of an import*, $\mathrm{PMS}_{i,r,s}$, is calculated as the bilateral *cif* import price plus the $1 import tariff imposed by the Chinese government, which sums to $13. With the addition of a $1 retail sales tax levied on shirt imports from all sources, Chinese consumers pay a *consumer import price*, $\mathrm{PM}_{i,s}$, of $14 for a Brazilian shirt.

Some Brazilian shirts are sold in its own domestic market. In this case, Brazilian consumers pay $8 plus any retail sales tax that the Brazilian government imposes. If we assume that the sales tax is $2 per shirt, then the price paid by Brazilians for a Brazilian-made shirt in Brazil (called the *consumer domestic price*, PD) is $10, which is the sum of the Brazilian producer price and the sales tax (Figure 2.5). Notice that the consumer price of the Brazilian shirt is higher in China ($14) than in Brazil ($10); the difference is because

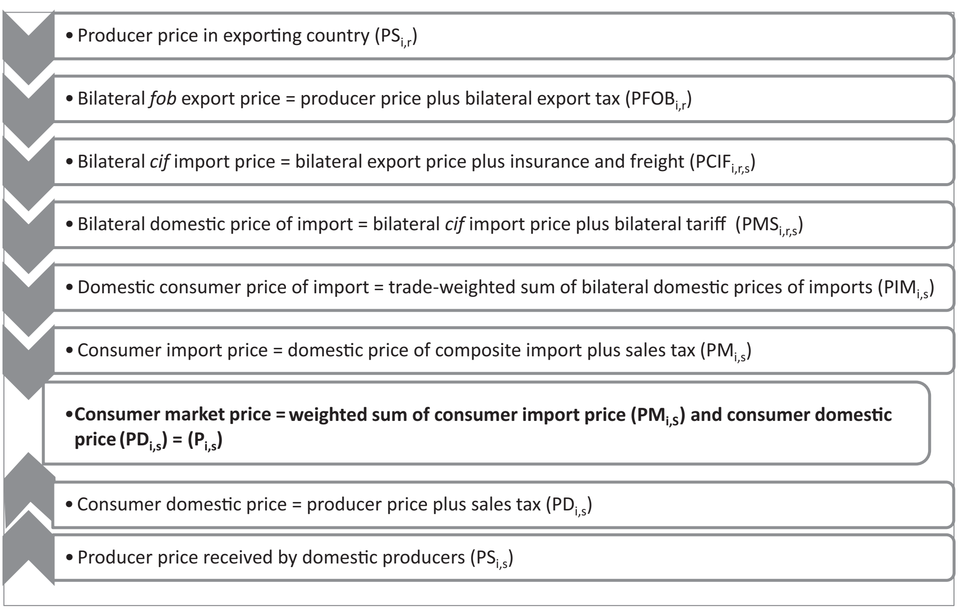


Figure 2.5 Price linkages in a standard CGE model.

of trade margin costs, import tariffs, export taxes, and the difference in sales taxes between the two countries.

Multi-country CGE models with bilateral trade flows report bilateral export and import prices for every commodity traded between every pair of trading partners in the model. Differentiating bilateral export and import prices allows the modeler to describe and analyse export taxes, tariffs, and trade margin costs that may differ among trade partners. It also allows the modeler to take into account that products are differentiated by country of origin. For example, Chinese consumers may think that shirts from Brazil are different than shirts from South Africa. As a result, China may import shirts from both Brazil and South Africa. There also can be two-way trade in the same product. For example, China may export shirts to Brazil at the same time that it is importing shirts from Brazil.

A CGE model keeps track of all bilateral prices and at times aggregates them into *composite prices*. A composite price is a weighted sum of prices. In our two-country example, we did not need a composite price for imported Chinese shirts because they were sourced solely from Brazil. In a multi-country model, it is useful to calculate a single composite import price that summarizes the prices of Chinese shirts imported from all sources.

As an example, let's calculate the composite *domestic consumer price of an import*, $\text{PIM}_{i,r}$, which is the trade-weighted sum of bilateral domestic prices of imports. A *trade weight* is the share of a source country in an importer's total import quantity, or the share of a destination country in an exporter's total export quantity. Suppose China accounts for 75% of Brazil's total quantity of imported apples, at a bilateral domestic import price of \$2 per apple (this includes *cif* trade value plus Brazil's import tariff on Chinese apples). Suppose the United States accounts for the remaining 25% of Brazil's apple imports, at a bilateral domestic import price of \$1 per apple. Brazil's domestic consumer price of its apple imports of \$1.75 is calculated as:

China's weighted bilateral apple import price(PMS)	$.75 * \$2 = \$1.50$
U.S. weighted bilateral apple import price (PMS)	$.25 * \$1 = \$0.25$
Brazil's domestic consumer price of imported apples (PIM)	$\$1.50 + \$.25 = \$1.75$

Other composite prices in a standard CGE model include a country's *world export price*, $\text{PWE}_{i,r}$, which aggregates the *fob* prices received for its exported product. It is calculated as the trade-weighted sum of all of its bilateral *fob* export prices for that product. For example, Brazil's world export price of shirts might be the trade-weighted sum of its bilateral *fob* export prices of shirts sold to China, Israel, France, and all other countries to which it exports. Likewise, a country's *world import price*, $\text{PWM}_{i,r}$, aggregates the bilateral *cif* prices it pays for its import of a product. It is the trade-weighted sum of its bilateral *cif* import prices, where the weights are the shares of each of its suppliers in the quantity of its imports. The *world price*, PXW_i, of a good, such as shirts, is the trade-weighted sum of all of the bilateral, *fob* export prices of all countries in the world. The weights are the shares of each bilateral trade flow in the total quantity of global trade in that good.

Finally, the *consumer market price* (P) of a good is the weighted sum of the *consumer import price*, which includes any sales taxes imposed on imports, and the consumer domestic price. The weights are the quantity shares of the imported and the domestic varieties in the consumer basket.

An important implication of the price structure and the supply and demand behaviour in a CGE model is that *price transmission* is limited. That is, a $2 increase from $5 to $7 in the producer price of Brazilian shirts may translate into an increase of less than $2 in the consumer market price of shirts in China.

For example, let's assume that imports account for 50% of China's shirt consumption. Brazilian shirts account for 50% of the imports, at a bilateral domestic price of imports of $5 and the United States accounts for the remaining 50% of China's import market, also at a price of $5. The domestic variety, which accounts for 50% of China's consumption, is supplied at the consumer domestic price of $5. To simplify, we assume there are no trade margin costs, taxes or tariffs.

The example in Table 2.2 illustrates the effect of Brazil's $2 price hike on China's consumer price, which increases by $1.06. Notice that in the new equilibrium, both the market shares and the prices from competing suppliers also have changed in response to the producer price increase in Brazil. Brazil's market share in China falls because Chinese consumers substitute toward the cheaper, competing domestic and U.S. varieties. These shifts in demand cause the prices of Chinese and U.S. shirts to increase.

Table 2.2. *Calculating Price Transmission in a CGE Model*

	Base Values for Market Shares and Prices	Updated Values for Market Shares and Prices
Bilateral domestic price of import – Brazil shirt (PMS)	$5.00	$7.00
Bilateral domestic price of import – U.S. shirt (PMS)	$5.00	$6.00
Consumer import price (PM)	$.5 * \$5 + .5 * \$5 = \$5.00$	$.3 * \$7 + .7 * \$6 = \$6.30$
Consumer domestic price (PD)	$5.00	$6.00
Consumer market price (P)	$.5 * \$5 + .5 * \$5 = \$5.00$	$.2 * \$6.30 + .8 * \$6 = \$6.06$

One way to describe our result is that "about 50% of Brazil's producer price hike is transmitted to Chinese consumers." Another way is to calculate the *elasticity of price transmission*. This is defined as the percent change in one price for a given percent change in another price. In our example, the elasticity of price transmission is the percentage change in China's consumer market price of shirts from \$5 to \$6.06 (21%) relative to the percentage change in Brazil's producer price of shirts from \$5 to \$7 (40%): $21/40 = .53$.

The elasticity of price transmission is different from the other elasticities that we have studied in this chapter. Whereas those elasticities are fixed in value and govern the supply and demand behaviour in the CGE model, this elasticity is a descriptive statistic that describes the results of a price shock in a CGE model. Such price transmission impacts are an important subject of CGE-based analyses, particularly for small countries that must adjust to external price shocks. In general, the transmission of a price shock in country A to country B is higher the lower the values of the CGE model's elasticity parameters and the higher the share of country A in the imports of country B.[6]

Numeraire

A CGE model describes only relative prices. To express all prices in relative terms, the modeler chooses one price variable in the CGE model to remain fixed at its initial level. This price serves as the model's *numeraire*, a benchmark of value against which the changes in all other prices can be measured (see Text Box 2.4).

As an example, consider a model with three goods: agriculture, services, and manufacturing. The producer prices of manufactured goods and services could be measured in terms of – or relative to – the price of the agricultural good, which we have selected to be the numeraire. Initially, the producer prices of all three goods are \$1 because they have been normalized. Let's assume that after a model shock, the producer price of the numeraire (agriculture) remains at \$1 (it must because it is the numeraire), but the producer price of the manufactured good has doubled; the relative producer price of manufactures is now $\$2/1 = 2$.

Because the exchange ratios of all goods are specified relative to the numeraire, you can also compare the prices of non-numeraire goods – in this case, the price of manufactured goods relative to services. Assume that the price of services increased only 20%; then its relative price in terms of

[6] See Siddig and Grethe (2014) for a clear and systematic exposition of how elasticity parameters and trade shares in a CGE model are related to the size of international price transmission.

Text Box 2.4. The Numeraire and Walras's Law

CGE modelers can be more confident that their model has a feasible and unique solution if it is "square" – that is, if the number of variables and equations in the model are equal. When we fix one price to serve as the numeraire, we are dropping one variable from our model. Are we therefore causing the number of variables to be one fewer than the number of equations? The answer is no, and it rests on Walras's Law.

Leon Walras was a nineteenth-century economist who studied the interconnectedness among all markets in an economy. He focused in particular on the problem of whether a set of prices exists at which the quantity supplied is equal to the quantity demanded in every market simultaneously. His theoretical, general equilibrium model was much like the standard, "Walrasian" CGE model that we are studying. They share the features that: (1) producers are profit maximizers who sell their goods in perfectly competitive markets at zero economic profit; (2) consumers are utility maximizers who spend all of the income they receive from their production and sale of goods; and (3) prices adjust until demand for each commodity is equal to its supply. Based on these assumptions and market-clearing constraints, Walras's Law states that, for the economy as a whole, the aggregate value of excess supply in the economy must be matched by the aggregate value of excess demand. This is essentially because producers plan to sell that value of goods that will enable them to afford their desired purchases. A shortfall in their actual sales (excess supply) therefore results in an equal shortfall between their actual and desired consumption (excess demand).

An implication of Walras's Law is that equilibrium in the last market follows from the supply-demand balance in all other markets. As a result, the equations in his model were not all independent. One equation was redundant and had to be dropped – but this meant his model had one more variable than the number of equations. Walras's solution was to fix one price in the model to serve as numeraire, making his model "square" once again. He could now solve for the market-clearing set of relative prices.

To make their models square, CGE modelers, too, usually drop one equation and fix one price variable to serve as numeraire. Any equation can be dropped without influencing results if the model is homogenous of degree zero in prices (as they usually are). In practice, modelers usually omit the macroeconomic market-clearing equation that defines aggregate savings (S) to be equal to aggregate investment (I). As an alternative, some modelers fix a numeraire but keep the redundant equation and add an additional variable called "Walras," that is, $S = I + Walras$. If all markets in the CGE model are in equilibrium, then the Walras variable's value will equal zero. Such a variable can be useful to the modeler as a way to check that all markets are in equilibrium in the base data and model solutions.

agriculture is $1.20/1 = 1.20$. The price of services (1.20) has fallen relative to manufacturing (2).

You can choose any price in the CGE model to be the numeraire. Your choice of numeraire has no impact on real, or quantity, variables that result from an experiment. Some modelers define the numeraire to be the consumer price index (CPI), which is calculated as the weighted sum of initial consumer prices, where the weights are each good's base budget share in the consumption basket. Other modelers select a producer price index or an index of the prices of domestically produced, nontraded goods. In the GTAP model, the default numeraire is an index of global wages and rents for labor, capital, and other factors.

Structure of a CGE Model

The programming code of a CGE model can be lengthy, so it is a common practice to organize it into a small number of blocks that accomplish different tasks.[7] Although this organization can vary among models, the structure of most CGE models and the steps required to run the model and an experiment are similar to those described in Figure 2.6.

A CGE model often opens with one or more blocks of code whose task is to introduce and define each of the sets, exogenous and endogenous variables, and exogenous parameters used in the model. The modeler must define each

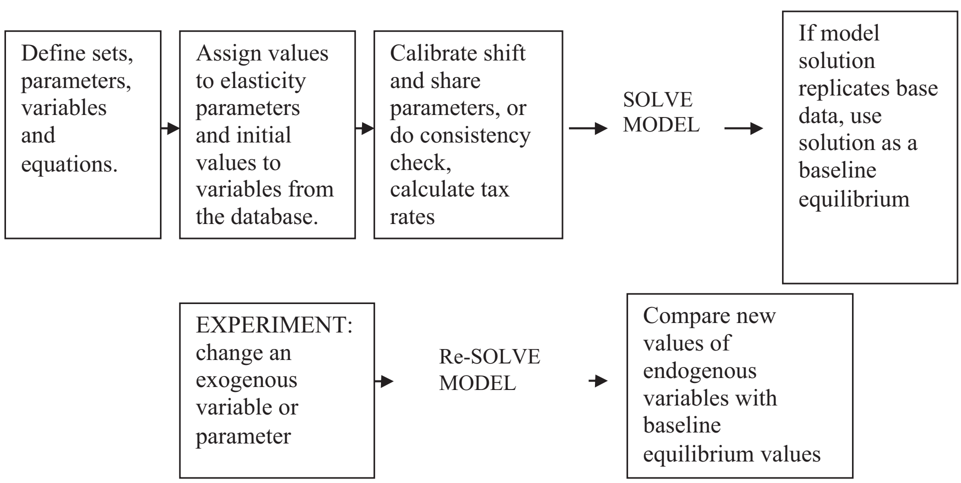


Figure 2.6. Structure of a CGE model and experiment.

[7] Models get more complex as their analytical capabilities are enhanced. Two examples of relatively simple CGE models are the Cameroon model developed by Condon et al. (1987), and the ERS/USDA model developed by Robinson et al. (1990). Both can be downloaded from the GAMS model library at www.gams.com. Students can run the models by downloading a demonstration version of GAMS software.

of these elements in the model code before the model can recognize and use them.

For example, model code may define an endogenous variable, the quantity of imports of commodity *i*, as:

$$\mathrm{QM_i} = \text{quantity of imports of commodity i}$$

Once the model code defines the variable $\mathrm{QM_i}$, all subsequent model code, such as equations, can recognize it. If an equation or other types of model commands refer to a set, parameter, or variable that has not yet been defined, the model will fail to solve.

Next, a CGE model has programming code whose task is to assign initial values to variables from the model database and to define elasticity parameter values. For instance, now that $\mathrm{QM_i}$ has been defined, values from the database can be assigned to its set elements, such as:

$$\mathrm{QM}_{\text{“Agriculture”}} = 552$$

Once sets, parameters, and variables have been defined and values have been assigned, the model can be calibrated or a consistency check can be carried out. Results of the calibration or consistency check are a baseline solution to the model that should exactly replicate the equilibrium described in the initial database. The CGE model equations are now numerical equations, similar to our bicycle model.

At this point, the modeler is ready to carry out an experiment. An experiment involves changing the value of at least one of the exogenous parameters or variables, such as the import tariff on agricultural imports. This change – a “shock” – is a controlled experiment in which the only change in the economy is the value of the exogenous parameter or variable, as specified in the experiment. The modeller re-solves the model, which recalculates new equilibrium values for all endogenous variables. The new solution values for the endogenous variables are compared with the baseline solution values. The resulting changes in variables’ values, such as a 5% decline in the quantity of imports compared to the base value, describe the effects of the economic shock on the economy.

Summary

In this chapter, we described the elements of standard CGE models, focusing only on their mechanics and leaving the study of their economic behavior for Chapters 4–9. For many students, this chapter can serve as a practical reference guide that you can return to as your modeling skills progress and questions arise.

CGE models of all types share many common features. They include behavioral equations that describe the behavior of producers and consumers, identity equations that describe accounting relationships and impose market-clearing constraints, and macroclosure rules that govern the savings and investment balance. CGE models follow the convention of normalizing prices so that the value data in the model database can be used to describe changes in both prices and quantities. CGE models report several prices for a single good because the models track prices at all points in the supply chain that links producers and consumers. All prices in the model are relative and expressed in terms of the numeraire. CGE models contain both linear and nonlinear equations; for small changes, nonlinear equations can be expressed in linearized form without loss of accuracy. In most CGE models, the program code first defines the names of the sets, endogenous and exogenous variables, and exogenous parameters used in its equations. Next, the model assigns numerical values from the database to all variables and defines elasticity parameter values. Blocks of equations then describe the model's economic behavior. The model is first calibrated or a consistency check is carried out. These procedures utilize model equations and the initial database to yield a model solution that replicates the initial base data. This solution becomes the baseline equilibrium against which the results of experiments are compared.

Key Terms

Behavioral equation
Bilateral *fob* export price
Bilateral *cif* import price
Bilateral domestic price of import
Calibration
Complement
Composite price
Consumer domestic price
Consumer import price
Consumer market price
Cost, insurance, freight (*cif*)
Domestic consumer price of import
Elasticity, aggregate input substitution
Elasticity, commodity substitution in consumer demand
Elasticity, export demand
Elasticity, export transformation
Elasticity, factor mobility
Elasticity, factor substitution
Elasticity, import-domestic (Armington) substitution

Elasticity, import-import (Armington) substitution
Elasticity, income
Elasticity, intermediate input substitution
Elasticity, own price
Elasticity, price transmission
Endogenous variables
Exogenous parameters
Exogenous variables
Free on board (*fob*)
Identity equation
Independent good
Law of demand
Linearized equation
Luxury good
Macroclosure
Model closure
Necessity good
Nonlinear equation
Normal good
Normalized price
Numeraire
Price transmission
Producer price
Set
Share parameter
Shift parameter
Substitute
Tariff rate
Tax rate
Trade margin
Trade weight
Walras's Law
World export price
World import price
World price

PRACTICE AND REVIEW

1. Assume a set of consumer goods *i* with three elements: agriculture, manufacturing, and services. If P is the consumer price, use set notation to express these variables:

   Consumer price for set *i*________________________________
   Consumer price of manufactures________________________

2. If QM is import quantity, define QM ("AGR", "USA", "Brazil"): ___________
   ____

3. Review the role of supply elasticities in a demand shock.
   a. Draw a graph of the supply and demand for one good. Label the supply curve S^1 and the demand curve D^1. Label the axes and the initial equilibrium.
   b. Draw a second supply curve that shows the industry with a more elastic supply that has the same equilibrium as S^1 and D^1. Label the second supply curve S^2.
   c. Assume that an income tax cut increases disposable income and consumer demand. Draw a new demand curve, labeled D^2, and label the two new equilibria along S^1 and S^2.
   d. In no more than a paragraph, (1) explain the difference between the two market equilibria and (2) identify the elasticity parameters in a CGE model that can cause S^2 to be more elastic than S^1.

4. Review the role of demand elasticities in a supply shock.
   a. Draw a graph of supply and demand for one good. Label the supply curve S^1 and the demand curve D^1. Label the axes and the initial equilibrium.
   b. Draw a second demand curve that shows the consumer with a more elastic demand curve that has the same equilibrium as S^1 and D^1. Label it D^2.
   c. Assume a supply shock, such as favorable weather, that increases the supply of a good. Draw the new supply curve, labeled S^2, and label the two new equilibria along D^1 and D^2.
   d. In no more than a paragraph, (1) explain the difference between the two market equilibria and (2) identify the elasticity parameters in a CGE model that can cause D^2 to be more elastic than D^1.

5. Normalize prices.

   Assume that the apple sales quantity has increased by 50%. Calculate the percent change in the value of apple sales in the first row of Table 2.3. Next, normalize apple prices and quantities and calculate the percent change in value of sales. Demonstrate that this result is the same for both actual and normalized data.

Table 2.3. *Normalized Prices and Quantities of Apples*

	Base Values			50% Change in Quantity			
	Price	Quantity	Value	Price	Quantity	Value	% Change in Value
Actual	2	12		2	18		
Normalized	1			1			

6. Calculate a consumer import price.

   Use the data in Table 2.4 to calculate the U.S. consumer import price (PM) for corn.

Table 2.4. *Calculating the U.S. Consumer Import Price (PM) of Corn*

	France	Germany	South Africa
Exporter's market share of U.S. corn imports	50%	25%	25%
Exporter bilateral *fob* export price (PFOB)	$1.25	$0.85	$1.90
Trade margin	$0.25	$0.15	$0.10
U.S. bilateral *cif* import price (PCIF)			
Tariff cost	$.50	$0.40	$0.10
Bilateral domestic price of import (PMS)			
Trade-weighted domestic price of import (import share ∗ PMS)			
Bilateral domestic price of import (PIM) (sum of weighted PMS's)			
Sales tax cost	$0.12		
U.S. consumer import price (PM)			

7. Calculate a price transmission elasticity.

Assume that France's bilateral *fob* export price to the United States increases by 50% and causes a 10% increase in the U.S. consumer import price of corn. What is the price transmission elasticity between the French and U.S. prices?

3

The CGE Model Database

In this chapter, we describe the two components of the database of a computable general equilibrium (CGE) model. The first is the Social Accounting Matrix (SAM). The SAM database reports the value of all transactions in an economy during a period of time. The data are organized in a logical framework that provides a visual display of the transactions as a circular flow of national income and spending. The SAM's microeconomic data describe transactions made by each agent in a region's economy. When aggregated, the SAM's micro data describe the region's macro economy. The SAM's micro data can be used to calculate descriptive statistics on an economy's structure. A CGE model database also includes elasticity parameters that describe the responsiveness of producers and consumers to changes in income and relative prices. The role of these parameters in driving model results can be evaluated in a sensitivity analysis.

The database of a computable general equilibrium model has two components. One is the *Social Accounting Matrix* (SAM). The SAM database reports the value of all transactions in an economy over a specified period of time, usually a year. The SAM data are organized in a logical framework of rows and columns that provides a visual display of the transactions as a circular flow of national income and spending in an economy. The SAM that we use throughout this book, for demonstration, describes the economy of the United States in 2007. The second component of a CGE model database provides the elasticity parameters that describe producer and consumer responsiveness to changes in relative prices and income.

Until relatively recently, development of a database for a CGE model represented a time-intensive first step in a CGE-based analysis. Today, most CGE-based research draws at least in part on a global database of country SAMs and elasticity parameters that was developed and is regularly updated by the GTAP Center at Purdue University. The GTAP Center relies on individual researchers to contribute country data. The data are drawn from multiple sources, including national income and product accounts, international trade databases such as the United Nation's Comtrade, and other data sources that describe taxes, tariffs, and other government interventions. The GTAP Center then integrates and balances the country data contributions into a unified and internally consistent global database. In Model Exercise 1, you are introduced to the GTAP data and shown how to use its accompanying software to aggregate the large global database into a smaller database that focuses more narrowly on the countries and commodities that are the subject of your research. In the exercise, you will aggregate the GTAP database into the U.S.3×3 version used for demonstration throughout this book.

Introduction to the Social Accounting Matrix

The SAM is a logical arrangement of income and spending data that provides an easy-to-read, visual display of the linkages among *agents* in the economy. Agents typically include industries, factors of production (e.g., labor and capital), household consumers, the government, investors, and the rest-of-world region, which supplies imports and demands exports.

A SAM is a square matrix of data (see Text Box 3.1). It is square because every economic agent in the economy has both a column account and a row account. The SAM's column accounts record each agent's spending. Row accounts record each agent's sources of income. Therefore, every cell in the SAM matrix describes a single transaction as being simultaneously an expenditure by an agent's column account and the receipt of income by an agent's row account. This procedure for recording transactions visually records how any single transaction links two agents in the economy.

Table 3.1 shows a simple example of the SAM accounting framework. There are two agents: a farmer and a baker. Each agent has both a row account and a column account. The farmer's expenditure of $1 on bread is reported in his column (expenditure) account, "Farmer spending," and his income of $1 from the sale of wheat to the baker is reported in his row (income) account, "Farmer income." The baker's expenditure of $1 on wheat is reported in the column account "Baker spending;" and her income of $1

Text Box 3.1. Key Features of a SAM

- A SAM is a square matrix because each agent has both a column and a row account.
- Column accounts record spending.
- Row accounts record income.
- Each cell in the SAM is simultaneously an expenditure by an agent and a source of income to an agent.
- For each agent, total expenditure (column account total) must equal total income (row account total).

Table 3.1. *A Two-Agent SAM*

	Farmer Spending	Baker Spending	Total Income
Farmer income		Baker buys \$1 wheat from farmer	Farmer income = \$1
Baker income	Farmer buys \$1 bread from baker		Baker income = \$1
Total spending	Farmer spending = \$1	Baker spending = \$1	

from the sale of bread to the farmer is reported in the row account, "Baker income." Note that the \$1 the farmer spends on bread is simultaneously the \$1 earned by the baker on the sale of bread. This single cell therefore reports both sides of the same transaction. Finally, the incomes of the farmer and the baker of \$1 are equal to their expenditures of \$1.

The SAM format enables the modeler to verify visually that its data are balanced. A SAM is balanced when every agent meets this constraint: Total spending (its column sum) equals total income (its row sum). For example, by comparing the baker's column sum with her row sum, you may easily verify that her income of \$1 is equal to her expenditure of \$1. When income is equal to spending in every account, then the economy's aggregate spending is equal to its aggregate income, and the database describes an economy in an initial equilibrium. A CGE model requires a balanced database as an initial starting point. As we will see in later chapters, model shocks will disturb this equilibrium. Prices, supply and demand will then readjust until the economy is in a new equilibrium in which income again is equal to expenditure for all agents in the economy.

Accounts in a SAM

The SAMs used in CGE models usually contain more accounts than in our simple example of the transactions between the farmer and the baker. SAMs contain accounts that describe the supply and demand for all products and the incomes and spending of all agents in the model. Additional accounts describe income transfers among agents such as payments from governments directly to households. SAMs also include a financial account to describe the sources of national savings and composition of investment spending.

Throughout this book, we will study a SAM for the United States in 2007 (Appendix A Table). In this SAM, the circular flow begins with columns and rows that describe transactions related to U.S. imports. It does not matter in which order accounts are presented in a SAM, although it is the convention that the ordering of row accounts is the same as that of columns. The accounts included in SAMs often differ across CGE models. They may differ in dimensions – that is, in their number of industries, factors of production, or household types. For example, some SAMs may have accounts that divide an economy into two industries, such as mining and nonmining industries, while other SAMs may have accounts for 400 or more industries. The U.S. SAM that we study in this book has three industries – agriculture, manufacturing, and services; three factors – land, labor, and capital; and one household type. That is why we call it the U.S. 3×3 SAM.

SAMs' accounts can differ, too, because the structure and theory of the CGE models in which they are used differ. A SAM and its CGE model must be consistent with each other. For example, one CGE model may include a regional household while another model does not. Their SAMs will differ in that case – one SAM will include row and column accounts for a regional household while the other will not. Note, too, that even when the accounts of two SAMs are identical, the location of data in their cells can differ. This point is particularly important for tax data. Taxes' cell locations describe the transactions in the CGE model on which each tax is assumed to be levied. For example, in some SAMs (and their related CGE model) an income tax may appear as an expenditure in the private household's spending column that is paid to the government row account. Other SAMs (and their CGE models) may describe income tax as a payment from the labor and capital column accounts.

Studying the accounts and the cell locations of data in your SAM model is a good first step in learning about your CGE model. This study can help you identify both visually and intuitively the industries and agents in your model, their economic interrelationships, and the activities on which taxes are levied.

Table 3.2 presents a summary of the accounts typically found in SAMs. This summary, and the U.S. SAM that we will study, are compatible with the Global Trade Analysis Project (GTAP) CGE model, which we use for demonstration throughout this book. You can use the U.S. 3×3 SAM to follow along as we discuss each of the accounts in a SAM in detail.[1]

Commodities

Many SAMs begin with commodity accounts. A *commodity* is a *composite*, or aggregate, of an economy's combined supply of a good or service from imports and domestic production. Some SAMs (and their CGE models) preserve the distinction between imported and domestically produced varieties

[1] In a few instances in this chapter you will encounter "rounding errors." In Model Exercise 1, you will create a US 3×3 SAM that is expressed in millions of U.S. dollars, with six decimal places. The SAM's row sums exactly match their related column sums. To simplify our discussion in this chapter, we convert the U.S. SAM to billions of U.S. dollars, with zero decimal places. This inevitably introduces some rounding errors.

Table 3.2. *Accounts in a Social Accounting Matrix with a Regional Household*

	Commodities: Import variety	Commodities: Domestic variety	Production activities	Factors	Taxes	Regional household	Final Demand: Private households	Final Demand: Government	Final Demand: Savings-investment	Final Demand: Trade margins	Final Demand: Rest-of-world	Total
Commodities: Imports			Demand for imported inter-mediates				Demand for imports	Demand for imports	Demand for imports			Aggregate demand
Commodities: Domestic			Demand for domestic inter-mediates				Demand for domestic	Demand for domestic	Demand for domestic	Export of trade margins	Exports	
Production activities		Domestic production										Domestic sales
Factors of production			Factor payments									Factor income
Taxes	Import tariff	Export tax	Taxes on output, factor use, inputs	Income tax			Sales tax	Sales tax	Sales tax			Tax revenue
Regional household				Net factor income	Tax revenues							Aggregate income
Private household						Household income						Private household income
Government						Government income						Government income
Savings-investment				Depreciation		Domestic savings				Foreign savings	Foreign savings	Savings
Trade margins	Trade margins on imports										Foreign exchange outflow	
Rest-of-world	Imports											
Total	Aggregate supply		Gross domestic production	Factor expenditure	Tax expen-diture	Aggregate expenditure	Private consumption expenditure	Gov't. consumption expenditure	Gross investment expenditure	Foreign exchange inflow		

as they describe the supply and demand for each commodity.[2] For example, in the US3×3 SAM, the U.S. supply of the composite commodity "agriculture" is the sum of the imported agricultural variety plus the domestically produced variety of agricultural goods (see Appendix A Table). In 2007, the U.S. imported $34 billion worth of agricultural goods and produced $326 billion worth of agricultural products (shown as the column totals of the imports and domestic commodity columns). The total supply of the agricultural commodity was worth $360 billion.

The commodity row accounts describe the demand side of the model. Production activities, households, government, and investors all demand commodities, and some share of domestic production is used to satisfy export demand. In the U.S. SAM, for example, imported agricultural products are used as intermediate inputs into all three production activities. U.S. agricultural producers purchase $1 million worth of imported agricultural goods. Manufacturers ($15 billion) and service producers ($5 billion) purchase additional agricultural imports for use in their production processes. About $13 billion worth of agricultural imports are sold to private households. Notice that the row total of the agricultural import account ($34 billion) is equal to the account's column total. In other words, import supply is equal to import demand in the agricultural import account.

Likewise, the commodity row account for domestic agriculture describes the economy's demand for this good. In total, $221 billion worth of domestically produced agricultural products are used as intermediate inputs into the agricultural, manufacturing, and services production activities ($35 + $165 + $21 = $221 billion). In addition, the domestically produced agricultural product is sold to private households ($53 billion) and some is exported ($52 billion). In this account, too, the column sum of $326 billion (total supply) equals the row sum of $326 billion (total demand) (except for rounding errors).

Each of the domestic customers may demand different proportions of the imported and domestic varieties in their commodity bundle. In the U.S. SAM, for example, $15 billion of the imported variety and $165 billion of the domestically produced variety of the agricultural commodity (including sales taxes) are purchased by the manufacturing production activity. The import share in its use of agricultural inputs (including sales taxes) is $15/180 * 100 = 8.3\%$. Private households purchase $14 billion of the imported variety of agriculture and $55 billion of the domestically produced variety (including sales taxes). In this case, households import about 20% of their total agricultural consumption.

[2] Lofgren et al. (2002) and Breisinger, Thomas, and Thurlow (2009) provide illustrations SAMs that combine domestic and imported varieties into a single column and row for each product.

Production Activities

A production *activity* is a domestic industry engaged in the production of a good or service. The activity accounts in the SAM describe the supply side of the model. An activity's column account describes all of its expenditures on the inputs used and taxes paid in its production process. For example, the column account for the U.S. agricultural activity records its purchases of imported and domestically produced intermediate inputs. Intermediate inputs might include agricultural goods such as seeds, manufactured inputs such as fertilizer, and services such as bookkeeping. The remaining inputs – the sum of factor payments and all tax expenditures – are called an industry's *value-added*. The column sum for an activity is the value of its *gross output*. Gross output is value-added plus the costs of all intermediate inputs. In the U.S. 3×3 SAM for 2007, for example, the value of gross output by the agriculture production activity is $326 billion.

An activity's row account records where the industry sells its output. Production activities are usually assumed to sell their entire output to the domestic variety's commodity column account. You might think of the activity row account as the producer and the commodity column account as the wholesale packager who purchases goods and services from domestic producers and combines them with imported varieties to create composite commodities.

In most SAMs (and their related CGE models), each good or service has both an activity account and a matching commodity account. That is, if there is an electricity production activity account, there is also an electricity commodity account to which it is sold. However, this one-to-one correspondence is not necessary. Sometimes, the same good is produced in more than one way. Commercial agricultural production, for example, may use irrigation equipment whereas production of the same crop on small-scale farms relies on rainfall. A modeler interested in studying the two types of agricultural production can expand the SAM by dividing the agricultural production activity into two separate activity accounts, each with its own row and column. In our example, separate commercial and small-scale agriculture column accounts would report purchases of very different types of inputs, even though the two activities produce the same type of output. Their row accounts would report their sales of an identical product to the same domestic commodity account – "agriculture."

Modelers sometimes use this technique of subdividing activity accounts to create CGE models that subdivide a national economy into regions. For example, we could disaggregate a manufacturing production activity by all 50 U.S. states into 50 different activity columns and row accounts. A single commodity column account called "manufacturing" could purchase the same output, "manufacturing," from all fifty manufacturing production activities' row accounts. Text Box 3.2 describes a research project in which the CGE

Text Box 3.2. Disaggregated Production Regions and Households in a SAM for Morocco

"Policy Options and Their Potential Effects on Moroccan Small Farmers and the Poor Facing Increased World Food Prices: A General Equilibrium Model Analysis" (Diao, Doukkali, and Yu, 2008).

What is the research question? World food prices have increased sharply over recent years and do not appear likely to return to the 2000–2003 levels. How will higher food prices affect different production regions and household types in Morocco, which is dependent on food imports for a large share of its domestic consumption?

What is the CGE model innovation? The authors modify the IFPRI standard CGE model to account for disaggregated production regions and households in the SAM. They construct a SAM for Morocco that divides each agricultural production activity account into six agroecological regions, each with a different production technology to produce the same good. The household accounts in the SAM are disaggregated into ten representative groups consistent with the income deciles of rural and urban households.

What is the model experiment? World import and export prices of food are increased, based on price projections from the U.S. Department of Agriculture. Three mitigating policy options are modeled: (1) import tariff reforms, (2) import subsidies to the poor, and (3) compensatory direct transfer payments (negative income taxes) to poor households.

What are the key findings? Direct transfers to poor consumers, combined with increased public investment in agriculture to improve productivity, is a win-win strategy for Morocco's agricultural producers and consumers.

modelers subdivided the activity accounts of a SAM for Morocco to describe the production of the same agricultural good in different regions and using different production technologies.

Finally, some production activities can have multiple products, such as a livestock operation that produces beef and cowhides. In this case, the livestock activity row account could sell its output to separate beef and leather commodity column accounts.

Factors of Production

Factors of production are the resource endowments of land, labor, and capital that are combined with intermediate inputs such as steel, rubber gaskets, and electronic components to produce goods and services. The factors in the U.S. 3×3 SAM are land, labor, and capital. Some modelers further subdivide these factor types. For example, labor may be divided into skilled and unskilled workers, or land divided into cropland and forest, or irrigated and nonirrigated land. You can visualize the disaggregation of factors in a

SAM by imagining that there is a new factor column and a matching row account for each additional factor in the model.

The row account for each factor reports the income it receives from the production activities in which it is employed. Production activities pay wages to labor and rents to capital and land. In the U.S. 3×3 SAM, for example, the manufacturing production activity pays \$1,361 billion in wages to its labor force and \$649 billion in rents to capital equipment.

The factor column accounts report factor expenditure. In the U.S. 3×3 SAM, for example, the land column account reports that \$3 billion of its income is spent on income taxes and \$33 billion in after-tax land factor income flows to the regional household. The capital income account also reports payments to the income tax and regional household accounts but, in addition, it records capital depreciation of \$1,260 billion as an expenditure in the savings-investment row account. Depreciation is counted as a capital expense because it is the cost to firms of replacing the capital equipment that has worn out or become obsolete.

Taxes

The tax row accounts in a SAM describe the economic activities on which taxes are levied and the amount of tax revenue that is generated. For example, in the U.S. 3×3 SAM, production activities pay production taxes (from their column accounts) to the production tax row account. The agricultural production activity spends \$1 billion on this tax. Some taxes are reported as negative values, which denote a subsidy. For example, U.S. agricultural producers received a subsidy (that is, a negative sales tax) of \$1 billion on their purchase of domestic agricultural inputs in 2007. Tax row sums report the value of total revenue from each tax, which is paid in its entirety by the column account for each tax to the regional household account. In the U.S. SAM, for example, production taxes generated a total of \$581 billion in revenue and income taxes generated \$2,039 billion in revenue in 2007.

Regional Household

The *regional household* is a macroeconomic account found in some SAMs and CGE models.[3] It is very similar to the concept of GDP from the income side and from the expenditure side.[4] Its row account describes the sources

[3] Breisinger, Thomas, and Thurlow (2009), Reinert and Roland-Holst (1997), and Pyatt and Round (1985) offer introductions to SAMs without a regional household account.

[4] The regional household concept differs from GDP because it excludes depreciation, which is the cost in the current year of replacing capital that has been used up or worn out. Regional household income thus measures "net domestic product," which includes only new investment, net of depreciation, rather than gross domestic product, which includes gross investment spending on both replacement and new

of aggregate national income from factor incomes and taxes, and its column account describes aggregate domestic spending by private households and government, and national savings. In the U.S. 3×3 SAM, for example, the regional household accrues net factor incomes (after deducting factor income taxes and capital depreciation) along its row account: \$33 + \$6,463 + \$1,994 = \$8,490 billion. It also earns tax income from import and export taxes, sales taxes, and factor use, production, and income taxes, for a total regional household income of \$12,802 billion. The regional household column account shows how national income is allocated to spending by private households (\$9,949 billion) and government (\$2,258 billion) and to domestic savings (\$594 billion, combining private and public savings).

Private Households

The *private household* row and column accounts describe the income and spending of all of the individuals in an economy, aggregated into a single, "representative" household. The private household row account receives a share of the national income from the regional household's column account. Households spend this income in its entirety on goods and services and related sales taxes, as described in the household's column account. Private household consumption is usually a large component of an economy's final demand for goods and services. In the U.S. 3×3 SAM, for example, households spend \$9.9 billion, which far exceeds spending by government and investors.

Sometimes, SAMs (and their related CGE models) disaggregate the single household into several representative household types. They may be disaggregated according to criteria such as sources of income (perhaps one household type earns low-skilled wages and the other type earns high-skilled wages), or location (e.g., rural or urban), or expenditure patterns (e.g., high or low share of spending on food). Disaggregating households allows the modeler to analyze the distributional effects of an economic shock across different household types. For example, a new tax may benefit rural households but impose a burden on urban households.

You can visualize a SAM with many households by imagining that the single private household row and column accounts in the U.S. 3×3 SAM are disaggregated into *n* household row accounts and *n* household column accounts, each describing the different income sources and expenditure patterns of *n* household types.

capital goods. For example, in the U.S. 3×3 SAM, GDP is \$14,062 billion but regional household income is \$12,802 billion because it excludes depreciation of \$1,260 billion. Why is depreciation excluded? Investment spending to replace worn-out equipment does not add any new productive capacity to the economy.

Government

The government row and column accounts report government income and its expenditure on goods and services. In the U.S. 3×3 SAM, the government account receives $2,258 billion from the regional household and spends it almost exclusively on domestically produced services.

Savings-Investment

The savings and investment row and column accounts describe an economy's loanable funds market, showing the supply of savings that is available for investment and how these investable funds are spent. The row account reports the sources of a nation's savings. In the U.S. 3×3 SAM, the savings row account shows the accumulation of saving from domestic sources ($594 billion from private and public savings combined) and from foreign sources. Foreign savings ($773 + $58 = $831 billion) equals the trade balance in goods and services and in trade margin services. The row account also reports the depreciation of the existing capital stock ($1,260 billion), which is the investment spending by firms to replace the capital stock that is used up or worn out in the production process.

The investment column account records gross national investment, which is the combined spending on replacement of depreciated capital plus investment in new equipment and machinery that will be used in future production activities. The SAM reports the goods and services that investors purchase, but not the destination of those investment goods. For example, the U.S. 3×3 SAM reports that investors purchased $294 billion of imported manufactured products, but we do not know whether this new equipment will be installed in agriculture, manufacturing, or the services sector. In the U.S. 3×3 SAM, gross investment spending totals $2,686 billion. Some of the new capital goods replace the depreciated capital, and the remainder ($2,686 – $1,260 = $1,426) is net investment, or the net increase in the U.S. capital stock.

Trade Margins

The *trade margin* accounts describe the insurance and freight charges that are incurred when goods are shipped by air, sea, or overland from an exporting country to the importing country. These costs raise the price of imports relative to the price received by the exporters. The exporter's margin-exclusive price is called the free on board, or *fob price*. The importer's margin-inclusive price is called the *cif price*. The difference between the *cif* and *fob* values of imports is the trade margin.

In the SAM, there are trade margin accounts for both imports and exports. For imports, the trade margin row account records the freight and insurance costs incurred for each imported good. For example, the United States spends $5 billion on margin services to import $28 billion worth of agricultural products. It spends a total of $86 billion on trade margin costs on its imports. The exports trade margin column account reports the value of trade margin services produced by the United States and exported for use in global trade.[5] The United States exports $28 billion in margin services. Because trade margins are essentially the export and import of a type of service, a country has a balance of trade in trade margin services. It is the value of trade margin exports minus trade margin imports and reported as a foreign capital inflow or outflow in the savings-investment row. The United States has a trade deficit in margin services, resulting in a foreign savings inflow of $58 billion ($86 billion minus $28 billion).

Rest-of-World

This account describes trade and investment flows between a country and the rest of the world (ROW). The ROW's row account in the SAM shows the home country's (in this case, the United States) foreign exchange outflow, which is its spending on each import valued in ROW's *fob* world export prices. The ROW column account reports the home country's foreign exchange inflow, or export sales of each commodity, valued in the home country's *fob* world export prices. The column account also records the balance of trade as a payment by, or inflow from, the rest-of-world to the savings-investment account. The balance of trade is the difference between the *fob* values of the home country's total exports and total imports. When the country runs a trade deficit (its imports exceed its exports), its foreign savings inflow is positive. In this case, the country is borrowing from abroad and the foreign savings inflow increases its supply of savings. When a country runs a trade surplus (the value of its exports exceed the value of its imports), its foreign savings inflow is negative. In effect, it is lending its capital to foreigners. In the U.S. 3×3 SAM, imports of goods and services worth $2,139 billion and exports of $1,367 billion result in a foreign savings inflow to the United States (a trade deficit) of $773 billion (adjusted for rounding). The total U.S. trade deficit is the sum of its deficit in trade margins, goods, and other services ($58 + $773 = $831 billion).

Microeconomic Data in a SAM

A SAM database presents microeconomic data. Microeconomic data describe a nation's economic activity in detail. For example, the SAM's microeconomic data on production describe the amount spent by each industry on each type of intermediate and factor input, and each type of tax. Its data on

[5] Export margin data are not tracked bilaterally in the GTAP database from which our SAM is derived.

household demand describe expenditure on each type of commodity by that agent in the economy. Microeconomic data on trade describe the commodity composition of imports and exports. Even when the modeler chooses to summarize an economy into a relatively small number of industries or factors, we still consider the SAM to be a presentation of microeconomic data.

Macroeconomic Data in a SAM

Macroeconomic data provide a summary description of a nation's economic activity. Some of the row sums and column sums of the SAM are macroeconomic indicators. For example, the column sum of the private household account reports an economy's total private consumption expenditure, and the row sum of the ROW account reports total imports of goods and services. We can also aggregate other microeconomic data in the SAM to calculate descriptive macroeconomic statistics, such as the gross domestic product (GDP). Developing macroeconomic indicators from the data in a SAM is a useful exercise because it illustrates how the macroeconomic behavior of an economy rests on the microeconomic behavior of firms and households. (Text Box 3.3 provides an interesting example of a group of modelers who work in the opposite direction. In their research, they impose long-run growth projections for macroeconomic variables, such as the labor force, as an experiment, and then solve for the resulting microeconomic structure of the economy.)

In the following examples, we use microeconomic data from the U.S. 3×3 SAM to calculate three important macroeconomic indicators: GDP from the income and expenditure sides and the savings-investment balance.

GDP from the Income Side

GDP from the income side reports the sources of total national income from (1) the wages and rents that production activities pay to the factors (e.g., labor and capital) that they employ (reported on a net, or after–income tax, basis), and (2) total tax revenues in the economy:

$$\text{GDP} = \text{Factor income} + \text{tax revenue}$$

We calculate this macroeconomic indicator using data from the U.S. SAM's row accounts, which report income flows:

Factor payments = 9,749 =

Land factor payments: 36

Labor factor payments: 47 + 1,361 + 6,797 = 8,205

Capital factor payments: 53 + 649 + 2,846 = 3,548

Minus income taxes: 3 + 1,742 + 294 = 2,039

Text Box 3.3. Macroeconomic Projections in a CGE Model of China

"China in 2005: Implications for the Rest of the World" (Arndt et al. 1997).

What is the research question? In 1992, the Chinese economy was projected to triple in size over the next thirteen years. How will China's rapid growth affect its competing exporters in world trade and its import suppliers?
What is the CGE model innovation? The authors simulate the projected growth rates in macroeconomic variables (population, capital stock, and productivity) and analyze the resulting effects on the microeconomic composition of industry supply, demand, and trade in fifteen regions, including China, in the GTAP CGE model. The authors also carry out a systematic analysis of the sensitivity of their results to alternative values of import substitution elasticities, and they decompose welfare effects using the GTAP welfare decomposition utility.
What is the experiment? The experiment imposes cumulative projected growth rates of macroeconomic variables. The results describe the level and microeconomic structure of the fifteen economies in 2005. An alternative experiment assumes a lower growth rate of Chinese factor endowments that eliminates growth in its per capita GDP. The results of this alternative scenario for 2005 are deducted from those of the first scenario to identify the effects of China's rapid economic growth.
What are the key findings? Based on net-trade positions and likely changes in world prices, China's growth has an adverse impact on other developing countries. However, from a broader perspective that considers terms-of-trade benefits, efficiency gains, and factor endowment effects, China's growth benefits twelve of the other fourteen regions in the model, a result that is robust to a wide distribution of assumed trade elasticity values.

Plus taxes $= 4{,}312 =$

Import tariffs: $1 + 23 = 24$

Export taxes: 3

Sales taxes on imported variety: $1 + 59 + 0 = 60$ (from sales tax row totals)

Sales taxes on domestic variety: $1 + 204 + 58 = 263$ (from sales tax row totals)

Factor use taxes: $-1 + 1{,}232 + 112 = 1{,}343$ (from factor use tax row totals)

Production taxes: $1 + 70 + 511 = 581$

Income taxes: $3 + 1{,}742 + 294 = 2{,}039$

Thus, U.S. GDP from the income side is:

$$\text{GDP} = 9{,}749 + 4{,}312 = 14{,}062 \text{ billion (adjusted for rounding)}$$

GDP from the Expenditure Side

GDP from the expenditure side is a macroeconomic indicator that reports the allocation of national income across four aggregate categories of final demand: private household consumption expenditure, C, gross investment expenditure, I, government consumption expenditure, G, and net exports, E–M. You may recall this important equation, called the national income identity equation, from your macroeconomics studies:

$$\text{GDP} = \text{C} + \text{I} + \text{G} + (\text{E} - \text{M})$$

We calculate GDP from the expenditure side using data from the U.S. SAM's column accounts, which report expenditure flows:

$$\begin{aligned}
\text{C} &= \text{demand for commodities} + \text{sales taxes} \\
&= \text{total private consumption expenditure} \\
\text{C} &= (13 + 501 + 51 + 53 + 1{,}355 + 7{,}742) + (1 + 43 + 2 + 137 + 51) \\
&= 9{,}949 \\
\text{G} &= \text{demand for commodities} = \text{total government consumption} \\
&\quad \text{expenditure (governments usually don't pay tax)} \\
\text{G} &= 2{,}258 \\
\text{I} &= \text{demand for commodities} + \text{sales taxes} = \text{total investment expenditure} \\
\text{I} &= (294 + 4 + 764 + 1{,}604) + (5 + 12 + 1) = 2{,}686 \text{ (adjusted for rounding)}
\end{aligned}$$

The trade margin costs incurred in shipping goods to an importing country raises the costs of its imports. These margins are therefore included when calculating expenditures on imports. On the export side, a country's sale of the trade margin services used in global shipping is an export of a type of service, so, just like the export of any product, these sales are included in the value of its total exports. The GDP calculation excludes import tariffs and export taxes, however, because these are already embedded in the values of exports and imports reported in the final demand columns of the SAM.

$$\begin{aligned}
\text{E} &= \text{exports} + \text{exports of trade margins} \\
\text{E} &= (52 + 970 + 345) + 28 = 1{,}395 \\
\text{M} &= \text{exports} + \text{trade margins on imports} \\
\text{M} &= (28 + 1{,}797 + 315) + (5 + 81) = 2{,}226
\end{aligned}$$

Thus, U.S. GDP from the expenditure side is:

$$\text{GDP} = 9{,}949 + 2{,}686 + 2{,}258 + (1{,}395 - 2{,}226) = \$14{,}062 \text{ billion.}$$

Savings-Investment and the Balance of Trade

Recall from your macroeconomic coursework that by rearranging the expression for GDP from the expenditure side, we can derive this macroeconomic identity equation to describe the relationship between a nation's *domestic* savings, S_D, its investment spending net of depreciation, I_N, and its trade balance, E – M:

$$S_D - I_N = E - M$$

We can use data from the SAM to calculate the balance of trade and the savings-investment balance, and check that this relationship holds true in the U.S. 3×3 SAM, where:

S_D = domestic savings = 594, and
I_N = Investment spending minus depreciation = 2,686 – 1,260 = \$1,426

and (E – M) is already known from our calculation of GDP from the expenditure side. Thus, we can verify that in our database, the gap between domestic savings and net investment equals the trade deficit:

(594 – 1,426) = (1,395 – 2,226) = –\$831 billion (adjusted for rounding)

Structure Table

As a SAM's dimensions become larger, with an increased number of industries, factors, household types, or taxes, it becomes more challenging to fully understand or describe the complex economy that it depicts. (See Text Box 3.4.) One way to develop an overview of an economy without losing the detailed information available in the SAM is to construct a *structure table*. The table uses the microeconomic data in the SAM to describe the economy in terms of shares. For example, it reports the shares of each commodity in households' total consumption and the shares of each commodity in a country's total exports. Share data will enable you to make quick comparisons and to identify the most important features of the economy that you are studying. You are likely to find yourself often referring to your structure table as you define experiments and interpret your model results.

Table 3.3 presents an illustrative structure table constructed from the data in the U.S. 3×3 SAM. We can use the structure table to make observations like these about the U.S. economy:

- The United States now has a service economy. Services account for 81% of GDP, 83% of labor employment, and 79% of household spending.
- U.S. services is a relatively labor-intensive industry; labor accounts for a larger share (43%) of its production costs than in any other U.S. industry.

Table 3.3. *Structure Table for the United States in 2007*

	Industry GDP $US billion	Industry Shares in GDP	Factor Shares in Industry Costs			Industry Shares in Factor Employment		
			Land	Labor	Capital	Land	Labor	Capital
Agriculture	136	1	11	16	16	100	1	1
Manufacturing	2,547	18	0	24	43	0	16	18
Services	11,379	81	0	43	16	0	83	80
Total	14,062	100	na	na	na	100	100	100
	Commodity shares in:						Import Share of Domestic Consumption	Export Share of Domestic Production
	Domestic Demand				Trade			
	Intermediate Demand	Private Household Consumption	Government Consumption	Investment Demand	Imports	Exports		
Agriculture	19	1	0	0	2	4	11	16
Manufacturing	38	20	0	40	84	70	25	15
Services	44	79	100	60	14	27	2	2
Total	100	100	100	100	100	100	na	na

Source: GTAP v.8.1 U.S. 3×3 database.

Text Box 3.4. Distributing National Effects to the State Level in a CGE Model of the United States

"Disaggregation of Results from a Detailed General Equilibrium Model of the U.S. to the State Level" (Dixon, Rimmer, and Tsigas, 2007).

What is the research question? The USAGE-ITC, developed at the U.S. International Trade Commission, is a recursive dynamic CGE model descended from the Monash and ORANI models of Australia. It has more than 500 U.S. industries and multiple U.S. trade partners. However, U.S. policymakers are often concerned with the impacts of national policies at the state level. Can an already large, national-level model be solved to also yield results for state-level variables?
What is the CGE model innovation? The authors develop a "top-down" approach to disaggregating national results to the state level. First, a static version of the CGE model is used to solve for variables at the national level, including employment, private and government consumption, trade, real GDP, and industry output and employment. Then, state-level results are computed using an "add-in" program. The program describes the impacts for each state as the change in the national-level variable plus a state-specific deviation term. This approach ensures that state-level impacts sum to the national level; however, the results at the state level do not feed back to affect national-level variables.
What is the model experiment? The authors test their approach using an illustrative experiment in which the United States removes all import tariffs and quotas.
What are the key findings? The authors focus on employment effects, concluding that differential employment impacts across states reflect not only the shares of industries in employment in each state but also states' proximities to ports and to other high- or low-growth states.

- The United States imports only 11% of its food supply and U.S. households spend only 1% of their budget on food.
- Trade is relatively important to U.S. manufacturing – imports account for 25% of total U.S. consumption of manufactured goods, and exports account for 15% of manufacturing output.

You can follow the steps described in the following sections to construct a structure table for the country that you are studying. We demonstrate how each type of indicator is constructed, using data from the U.S. 3×3 SAM as an example, and we explain how each indicator can be useful as you begin to run model experiments and interpret your results.

Industry GDP

The GDP for industry a is calculated from the SAM's activity and tax column accounts as:

$$\text{Factor payments by } a + \text{taxes on factor use, output, sales, and trade of } a$$

Using agriculture as an example, we can calculate the GDP for U.S. agriculture from data in the U.S. 3×3 SAM as:

Agricultural factor payments = 36 + 47 + 53 = 136
Sales taxes paid by agricultural activity on imported inputs = 0
Sales taxes paid by agricultural activity on domestic inputs = –1 – 4 = –5
Factor use taxes in agriculture = –1 + 4 –2 = 1
Production tax on agricultural activity = 1
Import tariffs on agriculture = 1
Export taxes on agriculture = 0
Sales tax on final demand for imported and domestic agriculture = 1 + 2 = 3
Total agricultural GDP = 136 – 5 + 1 + 1 + 1 + 3 = 136 (adjusted for rounding)

Industry Share in GDP

The share of industry *a* in total GDP is calculated as:

$$\text{industry } a\text{'s GDP/GDP} * 100$$

The share of U.S. agriculture in GDP is:

$$136/14{,}062 * 100 = 1$$

Thus, agriculture accounts for only 1% of U.S. GDP. The relative size of an industry in total GDP is among its most important economic characteristics. The larger its size relative to other industries, the greater the impact of a shock in that industry on the rest of the economy. Given the small size of agriculture in the U.S. economy, do you think that a policy shock, such as the removal of agricultural production subsidies, would have significant effects on the U.S. economy as a whole? Probably not, although it may be a difficult shock to absorb for those engaged in agriculture.

Factor Shares in Industry Cost

Factor cost shares describe which factors are most important in an industry's total production costs. For example, capital equipment such as drills and pumps typically account for a far larger share of the input costs of the petroleum extraction industry than does labor. Factor cost shares are calculated for each factor *f* for each industry *a* from data in the production activity column accounts. A factor's costs include the wages and rents that the producer pays directly to each factor plus factor use taxes such as Social Security, and total input costs are equal to the gross value of output:

$$\text{(factor payment plus factor use tax for factor } f \text{ in industry } a)/$$
$$\text{total input costs in industry } a * 100$$

As an example, we calculate the factor cost share for labor employed in the U.S. manufacturing industry as:

Labor cost share in mfg.

$$= \text{labor payment plus labor use tax in mfg./total input costs in mfg.} * 100$$

$$(1{,}361 + 205)/6{,}657 * 100 = 24$$

Thus, labor accounts for 24% of production costs in U.S. manufacturing.

Factor cost shares in an industry matter when there are shocks that change the relative price or the productivity of a factor. For example, consider an industry such as wearing apparel, which spends far more on wages than it does on capital equipment. If there is an increase in the labor supply that causes wages to fall, then the apparel industry's factor costs will fall by proportionately more than in the capital-intensive petroleum extraction industry, from our previous example. The apparel industry's proportionately larger factor cost savings are likely to lead to an increase in its output and in its size relative to the petroleum industry, depending on consumer demand.

Industry Shares in Factor Employment

Industry shares in factor employment describe where an economy's land, labor, and capital endowments are employed. The shares are calculated for factor *f* and industry *a* from the income data in the factor rows of the SAM:[6]

$$\text{Factor payment to factor } f \text{ in industry } a/\text{sum of factor payments to } f \text{ by all industries} * 100$$

Using data from the U.S. 3×3 SAM, we calculate industry employment shares for labor as:

Labor payment in agriculture/sum of activity payments to labor:

$$47/(47 + 1{,}361 + 6{,}797) * 100 = 1$$

[6] Most CGE models include data on the value of factor payments or earnings, but not factor quantities, such as number of workers or acres of land. We can only infer industry shares in employment from income data if we assume that all farm acreage, workers, and capital equipment receive the same wages and rents across all industries. In this case, each dollar that any production activity pays to a factor buys the same factor quantity. This is the simplifying assumption made in many CGE models. However, wages and rents are often observed to differ across industries. Many doctors, for instance, earn more per hour than do programmers. In this case, two production activities may pay the same amount of wages and rents but employ different quantities of workers and equipment. Some CGE models account for wage or rent differentials across industries, but their databases must also include factor quantity data.

Labor payment in manufacturing/sum of activity payments to labor:

$$1{,}361/(47 + 1{,}361 + 6{,}797) * 100 = 16 \text{ (with rounding)}$$

Labor payment in services/sum of activity payments to labor:

$$6{,}797/(47 + 1{,}361 + 6{,}797) * 100 = 83$$

Most U.S. labor is employed in services (83%) and just 1% is employed in agriculture.

Industry shares in factor employment are useful to know because the larger an industry's employment share, the larger the impact on the economy-wide wage and rent when there is a change in its production and factor demand. For example, with 83% of U.S. labor employed in the service sector, a decline in the production of services would likely have a larger effect on national employment and wages than would a decline of similar proportion in agricultural output. Less employment in services could cause the average U.S. wage to fall because the loss of even a small proportion of service jobs means that a relatively large share of the U.S. workforce must look for new employment.

Commodity Shares in Domestic Demand

Firms, private households, government, and investors usually demand different types of goods and services. For instance, all households purchase food, whereas investors rarely buy food and instead purchase a lot of heavy machinery and equipment for use in factories and other businesses. The shares of each commodity i (which includes domestic and imported varieties) in total spending by each agent d describe an economy's consumption patterns. Because sales taxes are part of the purchase price, the calculation of commodity shares also includes that tax.

Commodity shares for each agent and commodity are calculated from the spending data reported in the agents' columns in the SAM:

$$\text{Expenditure by agent } d \text{ on commodity } i \text{ plus sales taxes/}\\ \text{total consumption expenditure by agent } d * 100$$

Using private household spending on the manufactured commodity and data from the U.S. 3×3 SAM as an example, the share of the manufactured commodity in total private household spending is calculated as:

$$(501 + 1{,}355 + 43 + 137)/9{,}949 * 100 = 20$$

When consumption patterns differ among agents, the same shock can affect each of them in different ways. For example, if the same sales tax is levied on all private-sector purchases of services, the impact on households will be proportionately greater than on investors, because households consume more services than do investors, as a share of their spending. Alternatively, taxes may be levied in a targeted way based on consumption shares. For example, a tax code may be designed to impose higher sales taxes on the types of goods that are purchased mainly by businesses, or by high-income households.

Commodity Shares in Exports and Imports

Commodity shares in the value of total exports and total imports describe the commodity composition of trade. The shares of each commodity *i* in total exports are calculated from data in the SAM's column accounts for export margins and the rest-of-world. The export margins are included because margins are a type of service export. Export taxes are excluded because they are already embedded in the export value reported in the commodity row of the SAM:

$$\text{export of } i/\text{total commodity exports plus total margin exports} * 100$$

Using manufacturing as an example, and data from the U.S. 3×3 SAM, the share of manufacturing in total exports is:

$$970/(52 + 970 + 345 + 28) * 100 = 70$$

Thus, manufactured products account for 70% of total U.S. exports of goods and services.

The share of each commodity *i* in the value of total imports is calculated using data from the column accounts of the imported variety of each commodity. The calculation uses the *cif* value of imports, which is the import value plus trade margins but excluding import tariffs:

$$\text{Import value plus trade margin on import of commodity } i/$$
$$\text{total commodity imports plus total trade margins on imports} * 100$$

Using manufacturing in the United States as an example, its share in total U.S. imports is:

$$(81 + 1{,}797)/(5 + 81 + 28 + 1{,}797 + 315) * 100 = 84$$

Import Share of Domestic Consumption

The share of imports in the total value of consumption of commodity *i* by firms, private households, government, and investors combined determines the strength of the linkage between events in world markets and domestic consumers. Consider the effect of an increase in world oil prices. Countries that depend on imports for a large share of their domestic petroleum consumption would experience a greater shock to their economy than would countries that import very little oil. Calculating import shares of consumption must take into account the sales taxes paid on both the imported and domestic varieties of commodity c.

The import share of consumption of commodity i is calculated as:

> Total domestic demand plus sales tax for the imported variety of c/ total domestic demand plus sales taxes for imported plus domestic varieties of commodity $c * 100$.

Using U.S. manufacturing from the U.S. 3×3 SAM as an example, the import share in domestic consumption of the manufactured commodity is calculated from data in the commodity rows and sales tax rows:

$$\text{Total domestic demand for imports of mfgs.} = 1{,}117 + 544 + 299 = 1{,}960$$

where:

Intermediate demand for mfg. import = $(9 + 797 + 300) + (4 + 7) = 1{,}117$
Private household demand for mfg. import = $501 + 43 = 544$
Government demand for mfg. import = 0
Investment demand for mfg. import = $294 + 5 = 299$.

We leave it as an exercise for you to verify that the value of total domestic consumption of the manufactured commodity (imported plus domestic varieties) = 7,854. The import share of domestic consumption of manufactured goods is therefore:

$$1{,}960/7{,}854 * 100 = 25$$

Given a 25% share of imports in U.S. consumption of manufacturing, what do you think would happen if a foreign export tax causes the price of manufactured imports by the United States to rise sharply? The effect will probably be significant (and negative), because imports constitute a large part of aggregate U.S. demand for manufactures.

Export Share of Production

Similar to the case of imports, the share of exports in the total value of production of good j determines the strength of the linkage between world markets and domestic producers. Because the revenue that producers get from export sales includes export taxes (or subsidies), the calculation of the export share of production also includes that payment. In our SAM, export taxes and subsidies are already embedded in the value of exports. Export margins are not included as a cost to exporters, since these freight and insurance charges are assumed to be paid by importers. The export share of production of each good or service is calculated from data in the domestic commodity row, and the rest-of-world column in the SAM:

$$\text{Exports of good } j/\text{Activity output of } j * 100.$$

Using U.S. agriculture as an example, we calculate the export share of production as:

$$52/326 * 100 = 16$$

Because U.S. farmers export 16% of their output, how do you think they are likely to be affected by a real appreciation of the U.S. dollar? Because exports represent a somewhat large share of U.S. production, the impact is likely to be negative and rather important.

Updating the SAM

You may have noticed that the U.S.3×3 SAM we use for demonstration describes the United States in 2007, and perhaps you consider it somewhat dated. A SAM database is often older than the data used in other kinds of economic analysis because of the lagged availability of data and the complex process of creating a balanced global database from multiple national and international sources of data. However, the age of a SAM is not necessarily important, because CGE models are primarily structural models. Their strength lies in describing the shares of activities in an economy, as we do in the U.S. structure table, and in quantifying how an economy's structure changes in response to a shock.

However, there are at least two reasons why updating a SAM is warranted. One is to add better or more up-to-date information to the database while minimizing any changes to the structure of the economy as it is described in the SAM. The second is to describe structural changes that have occurred since the SAM was created, or that are expected to occur in the future, that will result in a changed economic environment for the shock that is under study.

In the first case, the researcher may have better information on tax and subsidy policies and wants to correct the rates reported in the SAM. Tax and subsidy policies can be updated using approaches such as the GTAP model's Altertax utility (Malcolm, 1998). This utility redefines the model closure and elasticity parameters so that changes in tax rates have minimal effects on the economy's initial economic structure or trade flows. To describe changes in an economy's structure, a modeler defines an experiment to introduce the source of the change, such as a productivity shock that reduces agricultural production. The results of the experiment describe a new, updated economic structure in which agriculture may have smaller shares in GDP, employment and exports. This updated structure becomes the new baseline equilibrium. The researcher can now run model experiments and compare results to the updated baseline.

Modelers often use the second technique to project a SAM into the future. They define a *baseline scenario* as a model experiment that imposes macroeconomic projections of growth in a region's factor endowments, population, and real GDP or productivity. Growth in these variables then causes changes in economic structure. For example, consumers may have a high income elasticity of demand for services but a low income elasticity for food items. As their economy grows, the results of the baseline scenario describe how its structure will change. Services may account for a larger share of national

Text Box 3.5. Baseline Scenario in a Stylized Update of a CGE Model Database

"Modeling the Global Economy – Forward-Looking Scenarios for Agriculture" (van der Mensbrugghe, 2013).

What is the research question? The World Bank supports the Envisage model, a recursive dynamic CGE model used to analyze forward-looking questions about the economics of natural resources, commodities, and climate change. Its baseline scenario describes the future global economy over the 2005–2050 period in the absence of policy and other interventions that address climate change. What macroeconomic projections should be used to describe the baseline scenario?
What is the CGE model innovation? Using the neo-classical growth model as a framework, the author defines projected growth in factor supplies and productivity that replicate the "Samuelson-Belassa effect" in which the real exchange rate appreciates in developing countries experiencing high growth. The causal chain stems from high-productivity growth in manufacturing that raises wages and increases demand for non-traded services, such as restaurant meals. If productivity growth in services is assumed to be slower than in manufacturing, then the price of non-traded services increases relative to manufactured products, which is, in effect, a real exchange rate appreciation.
What is the model experiment? The baseline scenario experiment draws annual labor and population projections from the United Nations over the 2005–2050 period, and the CGE model solves for annual capital stock growth as a result of savings and depreciation. Services productivity growth is calibrated to reproduce projected per capita GDP growth rates by 2050, manufacturing productivity growth is 2 percentage points higher than in services, and agricultural productivity growth is an average of 1% annually.
What are the key findings? A comparison of the baseline with a scenario that includes baseline projections plus climate change shocks describes the impact of climate change on the global economy in 2050. A key result is that world real GDP will be 0.7% lower in 2050 because of climate change.

output while the role of agriculture diminishes. Other baseline scenarios may describe future policy changes, with or without macro projections. For example, a researcher may want to study the effects of a country's entry into a free trade agreement while taking into account other scheduled changes in tax policies that will influence its trade relations. In this case, the baseline scenario experiment introduces the scheduled tax changes.

After building a baseline scenario, a modeler defines a counterfactual experiment. For example, the baseline scenario may impose macro projections to describe an economy in 2025. A counterfactual experiment imposes the same macro projections with the addition of a shock, such as a new tax. A comparison of the results of the baseline and counterfactual experiments describes the effects of the new tax on a 2025 economy.

Text Box 3.5 presents an interesting example of the design of the baseline scenario for the World Bank Envisage CGE model. The scenario results describe a stylized pattern of exchange rate appreciation and structural change in developing countries. Model exercises 9 and 10 demonstrate how to create a baseline scenario experiment.

Elasticities Database

A CGE model database includes elasticity parameters. Whereas a SAM presents a static picture of an economy's equilibrium at a point in time, the elasticity parameters help describe an economy's movement from one equilibrium to a new equilibrium following a shock. In Chapter 2, we studied eleven elasticity parameters. Not all CGE models include all of those elasticities. Your database will contain only those used in your model.

Some CGE modelers estimate their own elasticities specifically for their model and their policy question. More often, modelers choose the most appropriate parameter values for their model based on a careful review of relevant econometric studies that estimate supply-and-demand elasticities. What are important considerations when choosing elasticities for your model? Most of the CGE-based literature on elasticities has focused on the selection of import substitution elasticities. Our discussion, too, will focus on that elasticity, but keep in mind that many of these observations are also applicable to your selection of other elasticities.

Good rules of thumb for selecting your trade elasticities take into account recent innovations in their econometric estimation.[7] Early estimates of trade parameters were largely based on time series studies of the willingness of

[7] This discussion draws on Hillberry and Hummels (2013), who provide a critical review of the evolution in parameter estimation and derive guidelines for CGE practitioners, and Hertel et al. (2004a).

consumers to substitute imports for domestic goods. These import-domestic substitution (also called Armington) elasticity estimates were generally quite low – often about 1. This means that a 1% increase in the ratio of the import price relative to the domestic price increases the quantity ratio of domestic to imported goods by 1%, for a given level of imports. Usually, the elasticities assumed for substitutability among suppliers of imports were roughly gauged to be twice the value of the estimated parameters, or about 2.

There are a number of reasons why the estimated values for trade substitution elasticities are so unrealistically low. Many studies describe highly aggregated categories of commodities, such as "transport products," rather than studying individually the demand for planes, cars, trucks and other transport modes. Recent empirical work has demonstrated that the more detailed the commodities, the higher the estimated import substitution elasticities. Estimates also typically exclude the role of quality. Because higher quality often leads to both higher prices and higher demand, importers may appear to be relatively price-insensitive. In addition, estimates may measure the short-term rigidities in markets that characterize consumer responses to transitory price variations rather than the larger market changes that occur over the long term when policies are adopted permanently.

Much of the new generation of trade elasticity estimates is based on cross-section or panel data, using econometric techniques and models that help correct some of the downward biases of conventional time series estimates. These approaches generally estimate import-import substitutability among the foreign suppliers of an import rather than the import-domestic substitution parameter and have typically generated substantially higher estimates for these parameter values than the doubled values of the time series results. Hillberry and Russel find the median value of these import-import elasticities to be about 5.

Rules of thumb, then, are to prefer elasticities from studies that employ cross-section or panel estimation techniques, whose commodity and country composition are relatively detailed and as closely related to your CGE analysis as possible, and whose parameter values tend to be longer term (and larger) rather than shorter term (and smaller).

Given the importance of the choice of parameter values in a CGE-based analysis and the inevitable uncertainty about their validity, many modelers carry out a *sensitivity analysis* of their model results to alternative sizes of elasticities. First, they run their model experiment with their assumed elasticity parameter. Next, they repeatedly change the values of one or more elasticities and rerun the experiment. They then compare the new experiment results with the results of the first experiment to determine whether their findings hold true across a reasonable range of elasticity values.

Summary

In this chapter, we described the SAM, a logical format used to organize and display CGE models' databases as a circular flow of income and spending in an economy. The SAM is a square matrix because each of its accounts is described by both a row, which records income, and a column, which describes spending. Each cell of the SAM describes a transaction simultaneously as an expenditure by a column account and as an income source to a row account. A SAM is balanced when the total income for each account (its row total) is equal to its total spending (its column total). A balanced SAM describes an economy in equilibrium. The accounts and the location of data in the cells of the matrix vary among SAMs because a SAM corresponds to the structure and theory of the CGE model in which it is used. Using a three-industry, three-factor SAM for the United States in 2007 as an example, we calculated macroeconomic indicators and developed a structure table. The structure table is a useful way to summarize the microeconomic data in the SAM and informs experiment design and the analysis of model results. We considered the reasons for updating the SAM and we discussed the elasticities database and how to select elasticities.

Key Terms

Agent
Baseline scenario
cif (cost, insurance and freight) import price
Commodity
Depreciation
Factor of production
fob (free on board) export price
GDP from the expenditure side
GDP from the income side
Gross investment
Gross output
Intermediate input
Net domestic product
Net investment
Private household
Production activity
Regional household
Savings
Sensitivity analysis
Social Accounting Matrix

Structural model
Structure table
Trade margin
Value added

PRACTICE AND REVIEW

1. Using data from the U.S. 3×3 SAM (Appendix A table):
   a. What is the value of gross output of the manufacturing activity?
   b. What is the value added of the manufacturing activity?
   c. What is the GDP of the manufacturing activity?
   d. What is the total value of the intermediate inputs used in the production of manufacturing, excluding sales taxes?
   e. Verify that valued added and intermediate costs sum to the gross output of manufacturing.
   f. What is the total labor cost in the services industry?
   g. What is the labor share of industry costs in services?
2. Using data from the commodity columns and rows for agriculture:
   a. What is the value of the imported supply of the agricultural variety (including import tariff and import margin)?
   b. What is the value of the supply from the domestic agricultural variety (including export taxes)?
   c. What is the total, or aggregate, supply of the agricultural commodity in the United States?
   d. What is the value of U.S. agricultural exports (including export taxes)?
   e. What is the import share of private household agricultural consumption?
   f. What is the export share of agricultural production?
3. What are good rules of thumb for selecting the elasticities for your CGE model database?
4. Define a baseline scenario and explain how it can be used in a forward-looking analysis. Describe a study that you might carry out using a baseline scenario and a counterfactual experiment.

4

Final Demand in a CGE Model

In this chapter, we describe final demand by domestic agents – private households, government, and investors – and by the export market. Data in the Social Accounting Matrix (SAM) describe agents' incomes and the commodity composition of their spending. The computable general equilibrium (CGE) model depicts demand by domestic agents as a two-stage decision. First, consumers decide on the quantities of each commodity in their consumption basket. Second, an "Armington" import aggregation function describes their choice between domestic and imported varieties of each *commodity*. We survey functional forms commonly used in CGE models to describe private household preferences. We also introduce the concept of "national welfare," which is the monetary value of changes in a nation's well-being following an economic shock.

The U.S. economic stimulus package, implemented in the 2009 recession, was designed to increase government spending in order to compensate for sharp declines in spending by private households and investors, and in export sales. These four categories of demand – private households, investment, government, and exports – constitute the demand side of an economy. They are called components of *final demand*, since the goods and services that are consumed are in their end-use; they are not further combined or processed into other goods and services. An economy's structure can change when the categories of aggregate final demand change in relative size, because each type of final demand usually purchases different goods and services. For example, households purchase items like groceries and entertainment, whereas investors purchase mainly machinery and equipment, and governments mostly purchase services. The increased share of the government in U.S. final demand as a result of the stimulus program thus likely changed the types of goods demanded in the U.S. economy, at least in the short term.

In this chapter, we learn how the SAM's data describe each component of final demand. We then study how each final demand agent is assumed to behave in the CGE model. Our discussion in this chapter mostly focuses on commonalities among CGE models, including the concept of "commodities," the two- (or three-)stage budgeting decision, and the measurement of national welfare. CGE models differ widely in their descriptions of private households' consumption behavior, making it difficult to characterize a "standard" CGE model in this respect. Thus, we survey four functional forms commonly used in CGE models to describe private households' preferences, and we explain the differences among these functions that are of practical importance to the modeler.

Final Demand Data in a SAM

Table 4.1 presents data on final demand from the U.S. 3×3 SAM. The table reproduces the column accounts (omitting the rows with zeros) that record expenditures by domestic consumers – which include private households, government, and investors – and by the rest of world.

Consumers demand commodities, such as "agriculture," which are composites of the domestic and imported varieties of a good. In the U.S. 3×3 SAM, consumers' column accounts separately record their spending on the imported and domestic variety of each of the three commodities (agriculture, manufacturing, and services). For example, U.S. private

Table 4.1. *Final Demand Data in the U.S. 3×3 SAM ($U.S. Billions)*

	Private Household	Government	Savings-Investment	Trade Margin Export	Rest-of-World
Imports					
Agriculture	13	0	0	0	0
Manufacturing	501	0	294	0	0
Services	51	0	4	0	0
Domestic					
Agriculture	53	0	0	0	52
Manufacturing	1,355	0	764	0	970
Services	7,742	2,258	1,604	28	345
Sales taxes–imports					
Agriculture	1	0	0	0	0
Manufacturing	43	0	5	0	0
Services	0	0	0	0	0
Sales tax–domestic					
Agriculture	2	0	0	0	0
Manufacturing	137	0	12	0	0
Services	51	0	1	0	0
Savings–Investment	0	0	0	58	773
Total	9,949	2,258	2,686	86	2,139

Source: GTAP v.8.1 U.S. 3×3 database.

households spend a total of $66 billion on the agricultural commodity, composed of $13 billion worth of imported agricultural goods and $53 billion of the domestic variety. Private households also spend $1 billion on retail sales taxes on the imported variety and $2 billion on retail sales taxes on the domestic variety. The total value of private household expenditure on all commodities, including sales taxes, is $9,949 billion. The column accounts for the U.S. government and investors similarly report their total spending on commodities plus sales taxes.

The export trade margin's column account reports U.S. exports of insurance and freight services used in global trade, worth $28 billion. Expenditures reported in the rest-of-world's column account report foreign purchases of U.S. goods, worth $1,367 billion, which are valued in U.S. *fob* export prices (i.e., excluding freight and insurance charges). Both of these column accounts include, in addition, payments to the savings-investment row account. The payments report the balance of trade in margin services and in other goods and services. A positive value indicates a foreign exchange inflow (a balance of trade deficit), and a negative value indicates a foreign exchange outflow (a balance of trade surplus). In the U.S. SAM, the positive numbers signal that the United States has trade deficits in both trade margin services and in goods and services, which sum to $831 billion.

We can use the final demand data in the SAM to calculate *budget shares*. A budget share is the value share of a good in the consumer's total spending. For example, private households' spending on imported manufactured goods (including the sales tax) accounts for 5.5% of their total spending.

Income Data in a SAM

CGE models impose the constraint that spending on goods and services, taxes, and savings must equal income. You may recognize this model constraint from your microeconomic theory, in which spending is subject to a budget constraint. Indeed, you may recognize this constraint from managing your own finances, as you decide how to allocate your after-tax income to purchases and to savings. Because final demand is constrained by income in the CGE model, it is worthwhile also to examine the income data in a SAM.

Data in Table 4.2 report selected row accounts from the U.S. 3×3 SAM, which describe income flows. Income originates from the employment of factors by production activities. The land factor, for example, earns a total of $36 billion, paid from the activity columns to the land factor row. Of this amount, the land column account reports that $3 billion is spent on land-based income taxes and the remaining, after-tax income of $33 billion is paid to the regional household's row account. Labor earnings of $8,205 billion are

Table 4.2. *Income Flows in the U.S. 3×3 SAM ($U.S. Billions)*

	Total Production Activities	Land	Labor	Capital	Income Tax	All Other Taxes	Trade balance	Regional Household
Land	36							
Labor	8,205							
Capital	3,548							
Income tax		3	1,742	294				
All other taxes	1,994							
Regional household		33	6,463	1,994	2,039	2273		
Private household							9,949	
Government								2,258
Savings				1,260			831	594
Total	13,783	36	8,205	3,548	2,039	2273	831	12,802

Note: The production activities' column sums the agriculture, manufacturing, and services activities. The columns of the U.S. 3×3 SAM. Column sums may have rounding errors.
Source: GTAP v.8.1 U.S. 3×3 database.

also divided between income taxes and payments to the regional household. Capital earnings of $3,548 billion are paid to income taxes and the regional household and, in addition, are expended on savings. This payment measures firms' replacement costs for depreciated capital equipment and machinery.

The regional household's row account shows its accumulation of $8,490 billion in after-tax factor income ($33 plus $6,463 plus $1,994 billion), income taxes ($2,039 billion), and all other taxes combined ($2,273 billion). National income, excluding depreciation, therefore totals $12,802 billion. National income is then allocated by the regional household's column account to the three categories of domestic spending: Private households receive (and spend) $9,949 billion, the government receives (and spends) $2,258 billion, and $594 billion is allocated to domestic savings (this includes combined household savings and government savings).[1] The savings row account describes the sources of investment funds, including depreciation spending, domestic savings, and an inflow of $831 billion from foreign savers, due to the U.S. balance-of-trade deficit.

Two-Stage Domestic Final Demand

In some CGE models, domestic consumers make their consumption decision in two stages, depicted in Figure 4.1. In the first stage, shown at the top level in the figure, they decide on the quantity of each composite commodity in their consumption basket, such as the amount of food and the number of books. Their choice depends on their subjective preferences. For example, consumers may prefer a large quantity of food relative to books. These preferences are described by a *utility function*, an equation that quantifies how much utility, or satisfaction, consumers derive from any given combination of consumption goods. Given their utility function, consumers select the basket of goods that generates the maximum achievable satisfaction given the prices of the goods and the consumers' budgets.

In the next stage, consumers minimize the cost of their commodity bundle by deciding on the shares of domestic and imported varieties that comprise each commodity. For example, once a consumer has decided on the quantity of food in her basket, she next decides on the amounts of domestically produced or imported food that she prefers, given their relative prices. This

[1] In the GTAP model that corresponds to this SAM, the allocation of regional household income is determined by a Cobb-Douglas regional utility function that allows the expenditure shares of private households, government, and savings in national income to change as the cost of private utility changes. When incomes rise, the cost of private utility increases so the expenditure share of private households falls while those of government and savings rise. In most CGE models without a regional household account, private household income is equal to factor income, government income is equal to tax revenues net of transfers, and investment spending is equal to savings.

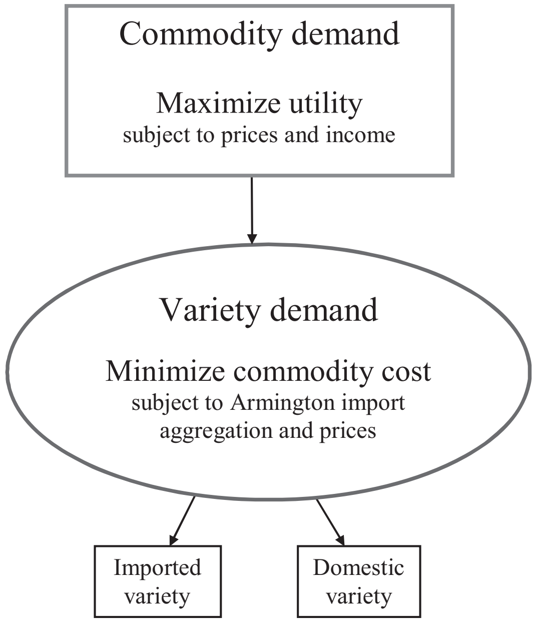


Figure 4.1. Two-stage domestic final demand.

decision is governed by an *Armington import aggregation function*, named after the economist Paul Armington (1969), who developed this type of sourcing decision in an applied economic model.

Some CGE models have a third stage that describes the lowest-cost sourcing of imports from alternative suppliers for a given quantity of a commodity import. For example, once the consumer decides on the quantity of imported shoes that he prefers, he then chooses the least-cost bundle of imported shoes from competing suppliers, such as Italy or Japan. Because this additional stage in consumer decision making is identical to that between the aggregate import and the domestic variety, for brevity, we omit further discussion of it. (See Text Box 4.1 for another example of an additional stage in consumer decision making, in this case related to the genetic attributes of food products.)

Most of our discussion in this chapter describes the utility-maximizing behavior of private households at the first stage of their consumption decision. We treat this stage of government and investment demand for commodities very briefly, since many CGE models describe their preferences in a simple fashion, by assuming that the initial budget shares in their consumption baskets remain fixed.[2] For example, if the government spends 10% of its budget on agricultural commodities, it will continue to spend 10% of any sized budget on agricultural commodities. Or, if agricultural prices rise by

[2] This is a Cobb-Douglas utility function. See Lofgren et al. (2002) for a discussion of alternative treatments of government and investment demand.

Text Box 4.1. Consumer Aversion to GM Foods

"Genetically Modified Foods, Trade and Developing Countries" (Nielson, Thierfelder, and Robinson, 2001).

What is the research question? Genetically modified (GM) seeds used in agricultural production have raised yields and increased pest resistance. Their use lowers production expenses by reducing the need for costly chemical and fertilizer inputs. However, some consumers, especially in developed countries, are concerned about the possible, unknown health effects of GM foods and prefer not to purchase them. How might consumer aversion to GM foods affect developing countries that produce and export these crops?
What is the CGE model innovation? The authors develop a database on trade and production of GM crops that they use to disaggregate the rows and columns of the SAMs' activity and commodity accounts for grains and oilseeds into GM and non-GM varieties. They also introduce an additional stage of the consumer budget allocation decision into an eight-region, global version of the International Food Policy Research Institute (IFPRI) standard CGE model. At the top level, a Cobb-Douglas utility function describes consumers as spending a fixed share of their budgets on grain and oilseed commodities. At the second level, a CES utility function describes consumers' choice between the GM and non-GM varieties of each commodity.
What is the model experiment? GM adoption is described as a 10% increase in total factor productivity and a 30% reduction in the use of chemical intermediate inputs in the GM grains and oilseed sectors. The authors present two alternative approaches to describe the aversion to GM foods by consumers in developed countries. First, they assume that consumers become less sensitive to prices, which is modeled as a reduction in the substitution elasticity between GM and non-GM varieties. Second, they assume a structural shift in demand by imposing a very low, fixed 2% budget share parameter for the GM variety. They reduce the share parameter by changing the base data in the SAMs and recalibrating the model.
What are the key findings? Adoption of GM crops provides farmers in developing countries with productivity benefits that lead to large welfare gains. Consumer preferences in developed countries do not diminish these gains, since bilateral trade patterns adjust, and GM and non-GM products are redirected according to preferences in the different markets.

10%, the government will reduce the quantity of agricultural goods that it purchases by 10% so that the agricultural budget share remains constant. This simple specification of government spending reflects the view that economic theory does not fully explain government outlays. In the case of investment, the standard, one-period CGE model that we are studying does not account for intertemporal calculations or expectations about the future that influence today's investment decisions. Consequently, this fixed-share allocation rule for investment demand is a transparent approach that simply replicates the demand for capital goods observed in the model's base year and reported in the SAM.

Utility-Maximizing Private Households

Private households in CGE models are assumed to be utility maximizers who allocate their income across commodities based on their preferences and subject to their budget and commodity prices. Most CGE models describe the behavior of a representative household that aggregates all of the households in a region. (See Text Box 4.2 for a description of a CGE model that disaggregates households.) To illustrate their behavior, suppose that a household consumer has a total income of $12 (and does not save or pay taxes) that it allocates to purchasing two commodities: apples, QA, with a price, PA, of $1, and oranges, QO, with a price, PO, of $2. Figure 4.2 describes the consumer's decision on how much to buy of each good. The downward-sloping straight line, Y, in the figure is the household's *budget constraint*. It shows all combinations of the two commodities that he can purchase for $12. For example, points on this line include such combinations as two apples ($2) plus five oranges ($10) for a total of $12; or ten apples ($10) plus one orange ($2) for a total of $12.

A budget constraint drawn to the right of Y represents expenditures greater than $12; a budget constraint drawn to its left represents expenditures of less than $12. A utility-maximizing household that earns $12 will always choose a basket of goods along its $12 budget constraint. More

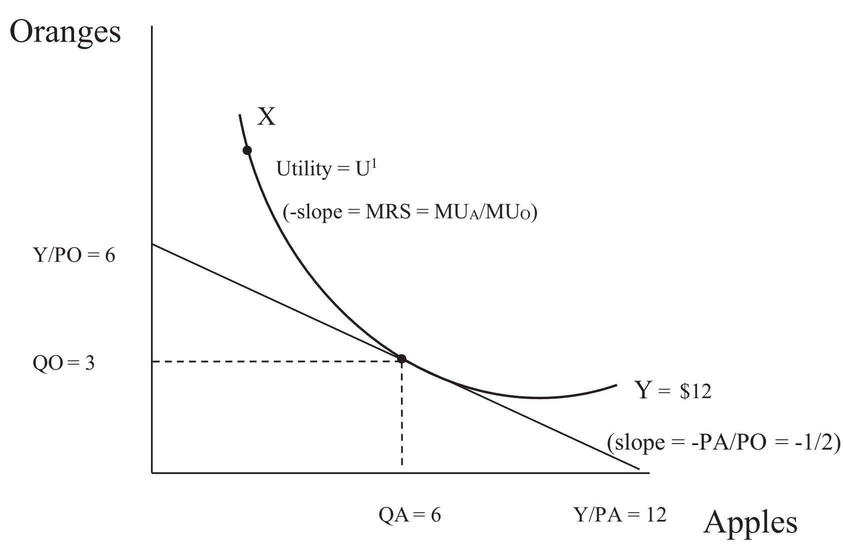


Figure 4.2. Consumer utility function with a budget constraint.

18:33:28,
.005

Text Box 4.2. A Macro-Micro CGE Model of Indonesia

"Representative versus Real Households in the Macroeconomic Modeling of Inequality" (Bourguignon, Robilliard, and Robinson, 2003).

What is the research question? CGE models with disaggregated households contain two or more "representative" household types. These models can describe differences in the income effects of economic shocks across types of households but imply that households within each type are all affected in the same way. However, household survey data show that changes in income inequality within each household type are at least as important as cross-type changes. Could a macro-micro analysis more realistically describe the effects of shocks on the distribution of income in a country?

What is the CGE model innovation? The authors combine the IFPRI standard CGE model with a micro-simulation model based on a survey sample of 9,800 households in Indonesia. They estimate reduced-form equations that explain households' work and occupational choices as a function of exogenous parameters such as wage, age, and education. The CGE model is solved for the effects of an economic shock on endogenous variables such as wages. These CGE model results are then used as the exogenous parameters in the equations of the micro-model to analyze impacts at the household level.

What is the model experiment? The authors explore two alternative macroeconomic shocks: a 50% decline in the world price of Indonesia's main commodity exports and a 30% decline in foreign savings inflows, similar to the effect of the 1998 financial crisis. Each CGE model scenario is run under three alternative government closures: the shares of government, investment, and private consumption in aggregate spending remain the same (suggesting a successful structural adjustment program); government spending adjusts to maintain the base government budget balance; and value-added taxes adjust to maintain the base government budget balance.

What are the key findings? The macro-micro model leads to distributional effects that are different in size, and sometimes even in sign, than a CGE model with representative households. The differences reflect that the macro-micro model accounts for phenomena that are known to be important in explaining household adjustments and resulting distributional changes, including changes in types of occupation, combinations of income sources, and differences in consumption behavior within household types.

is always better, but the household cannot afford to reach higher budget lines, and at lower budget lines it foregoes some achievable consumption. We observe this behavioral assumption of the CGE model in the model's SAM database in which, in the initial equilibrium, the income (the row total) for the household account is equal to its expenditure (the column total). This equivalence also will hold true in any post-shock model equilibrium.

If all income is spent on oranges, where Y meets the vertical axis, then quantity Y/PA, or $12/2 = 6$, oranges can be purchased. If all income is spent on apples, where Y meets the horizontal axis, then quantity Y/PA, or $12/1 = 12$, apples can be purchased. The slope of the budget constraint is calculated from the ratio of these two quantities (i.e., the rise over the run of the budget line) as $-6/12 = -1/2$. The sign is negative because the budget constraint is downward sloping; an increase in apples expenditure leads to a decrease in orange expenditure. Its slope can also be expressed as the price ratio of apples (the good on the horizontal axis) to oranges (the good on the vertical axis), since $-(Y/PO)/(Y/PA) = -PA/PO = -1/2$.

With so many feasible combinations that cost \$12, the household's choice of apple and orange quantities depends on how it ranks its preferences for goods and services – that is, its utility function. We can plot this function on a graph as an *indifference curve*, such as U^1 in Figure 4.2. The indifference curve shows all possible combinations of apples and oranges that yield the same level of utility. Indifference curves drawn to the right of U^1 represent higher levels of utility while those drawn to its left represent lower levels of utility.

The slope of the indifference curve describes the consumer's willingness to substitute apples with oranges, or the *marginal rate of substitution* (MRS). Imagine, for example, that the consumer has ten oranges and only two apples at point X on the indifference curve. Based on his preferences, the consumer would be willing to forego two oranges as he moves down his indifference curve and consumes one more apple, so the MRS of oranges for one additional apple is two. As the consumer moves further down his indifference curve, and quantity of apples consumed increases, he becomes more "apple satiated." His willingness to give up oranges in exchange for an additional apple diminishes and the MRS falls. We can also express the MRS as the ratio of the *marginal utility* of apples (i.e., the utility derived from consuming one more apple) to the marginal utility of oranges: MU_A/MU_O.[3] As more apples and fewer oranges are consumed, the marginal utility derived from eating yet one more apple falls, and the marginal utility derived from an additional orange increases as fewer oranges are consumed. The ratio MU_A/MU_O therefore falls as the consumer moves down his indifference curve.

3 The MRS is equivalent to the ratio of marginal utilities (MU_A/MU_O) because, if d refers to a marginal change, then the slope at any point on the indifference curve is $-dQO/dQA$, which is the rise over the run. The marginal utility of A is dU/dQA and of O is dU/dQO, so the ratio $MU_A/MU_O = (dU/dQA)\,/\,(dU/dQO) = dQO/dQA$, which is the negative of the slope of the indifference curve, or the MRS.

Consumers maximize their utility by choosing the combination of apples and oranges that provides the highest attainable utility curve given their budget constraint. In Figure 4.2, this is shown as the tangency between the budget constraint Y and indifference curve U^1, where the consumer chooses three oranges ($6) and six apples ($6) at a total cost of $12. At this tangency, the slope of the budget constraint (the ratio of prices) and the slope of the indifference curve (the ratio of marginal utilities) are equal: $MU_A/MU_O = PA/PO$. Rearranging, $MU_A/PA = MU_O/PO$. This means that the consumer maximizes utility when the marginal utility per additional dollar spent on each good is equal. If not, the consumer will spend more on the good that yields a higher marginal utility and less on the other good until their marginal utilities are equalized.

In some CGE models, household consumers are assumed to be cost minimizers instead of utility maximizers. They allocate their purchases to achieve a given level of utility with the minimum possible expenditure at given prices. Imagine that, in Figure 4.2, the consumer seeks the lowest attainable budget line with the slope $-PA/PO = -1/2$, while constrained to remain on the U^1 indifference curve. It should be evident that utility maximization and cost minimization are equivalent ways to describe consumer choice, and will yield the same ratios of demand quantities for a given level of utility.

Demand Response to Income Changes

Economic shocks in static CGE models usually lead to changes in income and in relative prices. Consumers respond by changing the quantities of goods and services that they purchase. We first consider the effect of income changes on quantities demanded. The indifference curve U^1 in Figure 4.3a describes the household's preferences for combinations of apples and oranges. The initial equilibrium is at the tangency of the budget constraint and the U^1 indifference curve, at quantities QO^1 and QA^1. An increase in income, holding relative prices fixed, shifts the budget constraint outward. It shifts outward in a parallel fashion, since the price ratio of oranges and apples has not changed. An increase in income allows the consumer to increase his purchases of both goods to quantities QO^2 and QA^2, and therefore to achieve a higher level of utility, U^2. An additional increase in income shifts the budget constraint out further, enabling the consumer to increase the quantities purchased and to achieve utility of U^3. Notice that Figure 4.3a describes a utility function in which income growth causes the quantity demanded of both goods to increase by the same proportion. For example, a 10% increase in income, holding prices constant, would result in a 10% increase in demand for both oranges and apples. This is a *homothetic* utility function with income elasticities of demand for goods equal to one. As income grows, with prices

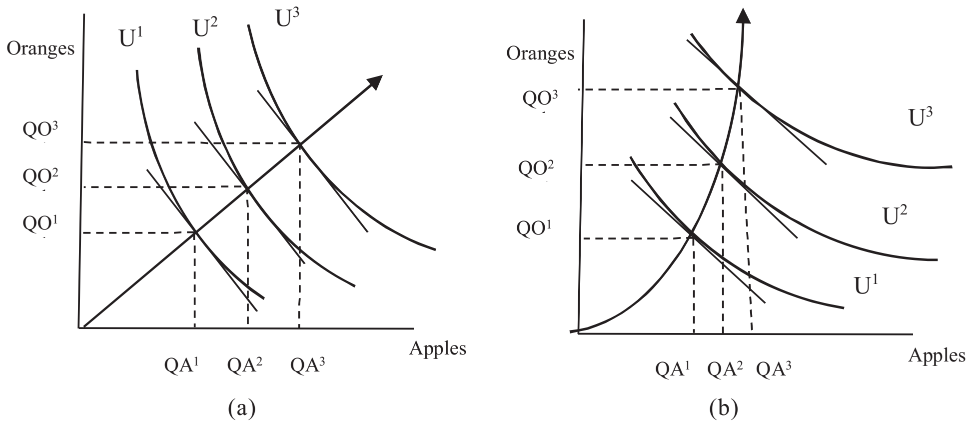


Figure 4.3. (a) Effects of income growth on consumer demand – homothetic utility function. (b) Effects of income growth on consumer demand – nonhomothetic utility function.

constant, an expansion path plots the locus of tangencies between the budget constraint and a mapping of successively higher indifference along a straight line emanating from the origin. Many CGE models assume homothetic utility functions.

Some CGE models assume *nonhomothetic* utility functions, such as that drawn in Figure 4.3b. Nonhomothetic functions allow income elasticities of demand to differ from one. Some goods may be *luxuries*, with income elasticities greater than one; others may be *necessities* with income elasticities of less than one. If oranges are a luxury and apples are a necessity, then income growth, with constant prices, will lead to an increase in the ratio of oranges to apples in the consumption basket. In this case, the expansion path veers toward oranges as income grows.

Demand Response to Relative Price Changes

Economic shocks in standard CGE models usually lead to larger changes in relative prices than in income, so it is worthwhile to examine carefully how demand quantities are assumed to respond to price shocks in these models. A key determinant is the *elasticity of substitution in consumption*, denoted by parameter σ^C. The elasticity expresses the percentage change in the quantity ratio of good Y to good X given a percentage change in the price ratio of good X to good Y. Returning to our example of apples and oranges, the larger is the elasticity of substitution, the more willing is the consumer to shift to apples from oranges as the relative price of apples falls.

Parameter σ^C describes the curvature of the indifference curve. When the parameter value is small, then the indifference curve is sharply convex, as in

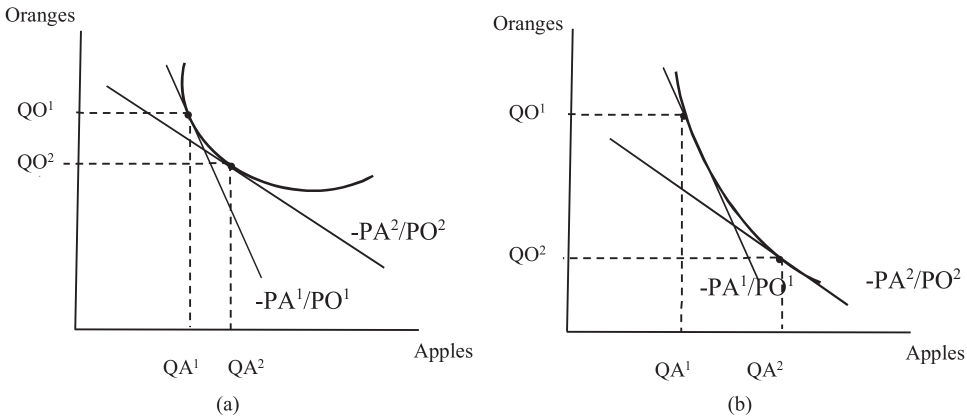


Figure 4.4. (a) Effects of price change on consumer demand, low substitution elasticity. (b) Effects of price change on consumer demand, high substitution elasticity.

Figure 4.4a. In this case, an outward rotation of the budget constraint, as the price of apples falls relative to oranges, causes a relatively small change in the consumption basket, from QO^1 and QA^1 to QO^2 and QA^2. Intuitively, the more curved the indifference curve, the faster the ratio of the marginal utility from an additional apple relative to that of an additional orange (MRS) falls as the ratio of apple to orange consumption rises. Therefore, the consumer is not very willing to give up oranges for an additional apple when the relative price of apples falls. When parameter σ^C is large, then the indifference curve is flatter, as in Figure 4.4b. The consumer will readily trade off oranges for an additional apple, with small effects on the fruits' relative marginal utilities. Therefore, the same decline in the relative price of apples will lead to a larger increase in the ratio of apples to oranges in the consumer's basket.

Sometimes, consumer preferences are quite rigid – for example, consumers usually buy right and left gloves in pairs. A fall in the price of right-hand gloves will not change the ratio in which gloves are purchased, since most consumers require right- and left-handed gloves in a fixed proportion. Such preferences are described by a Leontief utility function, whose elasticity of substitution is zero and whose indifference curve has an L-shape. Other consumers may be completely flexible in their preferences; for example, any brand of bottled water is equally satisfactory. If a consumer is always willing to trade off the same quantity of one good for the other, then the MRS between the products is constant. Because the goods are perfect substitutes, the elasticity of substitution approaches infinity and the indifference curve is drawn as a straight line.

We can decompose the effect of a price change on demand quantities into two components. First, if we assume that the own-price elasticity is negative, then the price change will cause consumers to shift the composition of their basket toward the cheaper good at any given level of utility. This is the substitution effect of a price change. It describes the movement of a consumer along the initial indifference curve as relative prices change, holding utility constant. Figure 4.5a illustrates the substitution effect of a price shock. In this example, the consumer initially purchases an orange quantity of QO^1 and an apple quantity of QA^1, at the U^1 level of utility. Suppose the price of apples falls to PO/PA^2, but the consumer is constrained to remain at the same level of utility. The dotted line, drawn parallel to the new price line, is the new price ratio. The substitution effect is the movement of the consumer along the initial indifference curve to the new basket of QO^2 and QA^2.

The second component is the effect of a price change on the consumer's purchasing power. If the price of apples falls, consumers now have money left over from purchasing their original basket. They can allocate this additional purchasing power toward buying more apples, more oranges, or more of both. The income effect of a price change measures the effect of the change in purchasing power on the consumption basket, holding relative prices constant. In Figure 4.5a, the income effect is the change from QO^2 and QA^2 to QO^3 and QA^3, at the new price ratio PO/PA^2.

By decomposing the income and substitution effects of a price change, we can describe apples and oranges as *net substitutes* (measuring only the substitution effect) and *gross substitutes* or *gross complements* (measuring the combined substitution and income effects). Two goods are net substitutes when a fall in the price ratio of good X to good Y causes an increase in the quantity ratio of good X to good Y, holding utility constant (i.e., remaining on the initial indifference curve). In our example in Figure 4.5a, apples and oranges are net substitutes because the fall in the relative price of apples causes the ratio of apples to oranges to increase, holding utility constant. CGE models typically assume that goods are net substitutes in consumption.

Two goods are gross substitutes if a decline in the price of one good causes demand for the second good to fall, and gross complements if demand for the second good rises. In Figure 4.5a, apples and oranges are gross substitutes. Although the income effect leads to increased demand for both fruits, the substitution effect dominates the income effect and causes the quantity of oranges demanded to fall when the price of apples declines. Figure 4.5b describes the case of gross complements. Oranges and apples are still net substitutes, but now the income effect dominates the substitution effect on oranges, so the quantity of oranges demanded increases when the price of apples falls. Gross complementarity is more likely to occur when the price change affects a good that is important in the consumer's total expenditure, so that purchasing power changes substantially: when income elasticities are large: or when the substitution effect is small because the indifference curve is very convex.

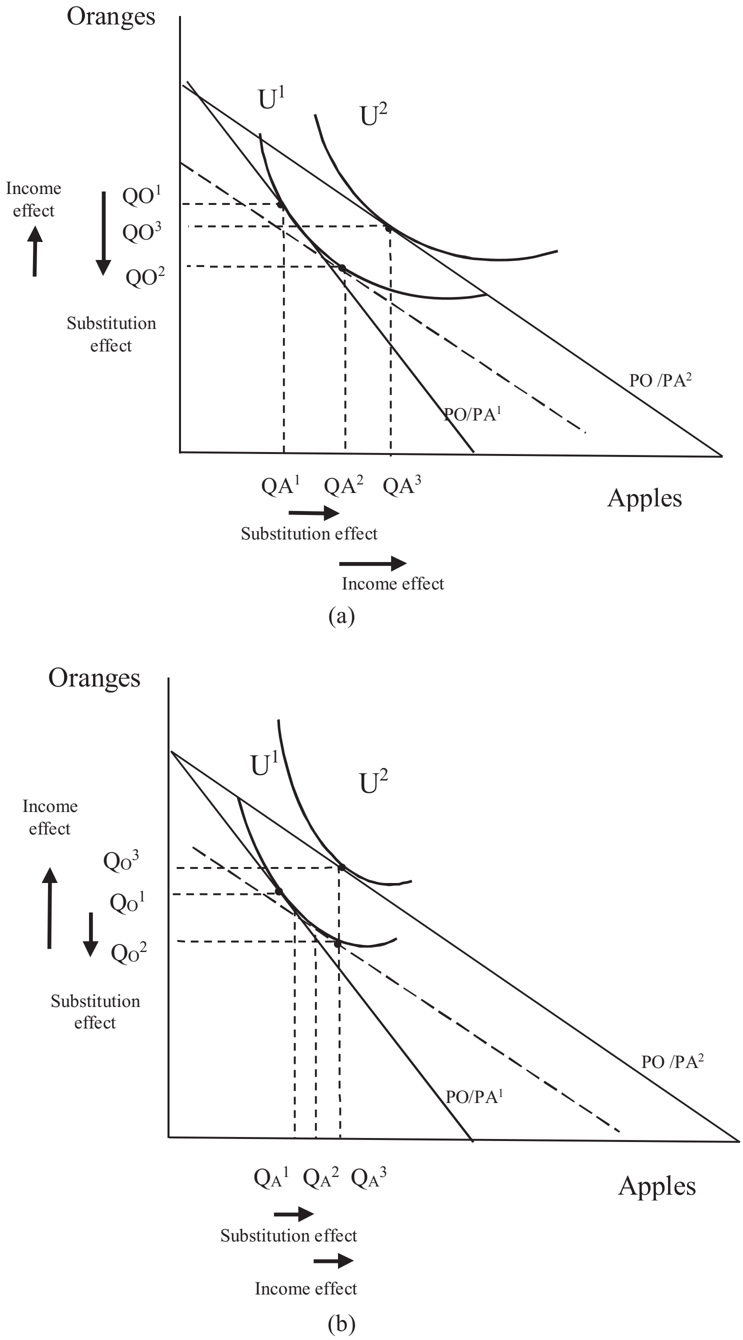


Figure 4.5. (a) Effects of price change on consumer demand – net and gross substitutes. (b) Effects of price change on consumer demand – net substitutes and gross complements.

Comparing Utility Functions Used in CGE Models

Our discussion of income and prices effects has emphasized how assumptions about consumer preferences, as described by utility functions and depicted in the curvature of indifference curves, determine how consumer demand responds to changes in income or in prices. CGE modelers therefore try to choose utility functions and elasticity parameter values that best describe consumer preferences in the economy that they are studying. Sometimes a modeler may need to trade off some degree of realism for feasibility when describing consumer demand. This is particularly true of modelers who want to use a standard CGE model and the utility function or demand system that it assumes, without extending the model's theory or programming. Flexibility to specify demand elasticity parameter values varies, too, since in some utility functions, these values are a "hard-wired" part of the functional form or constrained in the CGE model. For these reasons, it is useful for modelers to study the functional forms commonly used to describe consumer preferences in CGE models and to understand the practical implications for their model results.

We compare four functions that are widely used in standard CGE models: the *Cobb-Douglas*, *Stone-Geary/Linear Expenditure System (LES)*, *Constant Elasticity of Substitution (CES)* utility functions, and the *Constant Difference of Elasticities (CDE)* demand system (Table 4.3).

The simplest (but most restrictive) is the Cobb-Douglas utility function. The function itself implies values for elasticity parameters that the modeler cannot change. For all goods, the Cobb-Douglas own-price elasticity is –1, and the elasticities of substitution and income are 1. A unitary, negative own-price elasticity means that a change in price leads to an opposite change in quantity of an equal proportion. For example, a 10% increase in the apple price leads to a 10% reduction in apple quantity demanded. Because the quantity change in apples exactly offsets the price change, the apple budget share does not change. And since there is no change in spending on apples, the quantities of oranges and any other goods do not change either when the apple price falls. The function therefore implies that budget shares for all goods remain fixed as relative prices change. The homothetic Cobb-Douglas utility function also implies that, if income increases 10%, the quantities demanded of every good also increase by 10%. Therefore, the budget shares of each commodity in the consumer basket remain constant when incomes alone change. Because consumers make the same substitutions in response to relative price changes at any income level, all goods are also gross substitutes.

The other three functional forms allow the CGE modeler to define one or more elasticity parameters whose values lie within specified ranges (see the Technical Appendix to this chapter). The Stone-Geary utility function differs

Table 4.3. *A Comparison of Functional Forms That Describe Consumer Preferences in CGE Models*

	Elasticity			Budget Shares	
Utility Function	Income	Own-price	Substitution	Price Change	Income Change
Cobb-Douglas	Homothetic	Negative own-price	Net and gross substitutes	Fixed	Fixed
Stone-Geary/Linear Expenditure System (LES)	Quasi-homothetic	Negative own-price	Net substitutes, gross complements	Flexible	Flexible
Constant Elasticity of Substitution (CES)	Homothetic	Negative own-price	Net and gross substitutes	Flexible	Fixed
Constant Difference of Elasticities (CDE)	Nonhomothetic	Negative own-price	Net substitutes, gross substitutes or complements	Flexible	Flexible

Notes: We assume that the Frisch parameter in the Stone-Geary utility function is greater than –1, and the elasticity of substitution parameter in the CES utility function is greater than zero. See Technical Appendix 4.1 on parameter value restrictions.

from the Cobb-Douglas function in that it accounts for a minimum subsistence level of consumption, but above that level, preferences are described by a Cobb-Douglas utility function. For this reason, all goods are gross complements because an increase in the price of a good that meets minimum subsistence requirements means that the quantities of all discretionary goods must fall. Therefore, budget shares may vary. The Stone-Geary function is *quasi-homothetic* because only the demand quantities for goods that exceed subsistence levels change by the same proportion as income. Thus, budget shares of subsistence goods increase when incomes fall, and decrease when incomes rise. The smaller the share of subsistence goods in the consumption bundle, the larger the share of the bundle that is described by a Cobb-Douglas utility function, and the more homothetic the function becomes. Text Box 4.3 presents an interesting example of how the marginal budget shares in a Stone-Geary utility function are changed to describe a sudden consumer aversion to poultry meat.

The Constant Elasticity of Substitution (CES) utility function is homothetic but allows the modeler to specify explicitly the elasticity of commodity substitution parameter that defines the shape of the indifference curve. The name of the function, constant elasticity of substitution, derives from the fact that the substitution elasticity parameter has the same value at all points along its indifference curves and at all income levels. CGE models usually allow the modeler to define only one substitution elasticity parameter that describes identical pairwise substitutability among all goods in the consumption basket. Therefore, all goods are net substitutes (unless parameter σ^C is defined to be zero), and their budget shares may change when relative prices change. Because the utility function is homothetic, consumers make the same substitutions in response to relative price changes at any income level, so all goods are also gross substitutes.

An important and useful characteristic of the Constant Difference of Elasticities (CDE) demand system is that it is nonhomothetic. As incomes change, consumers can purchase proportionately more luxury goods and spend a smaller share of their budget on necessities, depending on the income elasticity of demand specified for each good. Its nonhomotheticity makes the CDE demand system especially well suited to analyze experiments in which there are large income effects. Commodities are net substitutes, but the presence of income effects means that goods can be either gross substitutes or gross complements. For example, a fall in the relative price of a necessity good with a large budget share is likely to shift consumption toward the necessity good, but the price savings will also provide a significant boost to a household's purchasing power. This income effect will cause the quantity demanded of luxury goods to increase and that of the necessity good to fall. If this income effect is large enough, the necessity and luxury goods can be

Text Box 4.3. Consumer Fear and Avian Flu in Ghana

"Economywide Impact of Avian Flu in Ghana: A Dynamic CGE Model Analysis" (Diao, 2009).

What is the research question? HPAI H5N1 (also known as avian flu) has attracted considerable public attention because the virus is capable of producing fatal disease in humans. Control measures have focused on its prevention and eradication in poultry populations by culling flocks, but this has not prevented a sharp fall in poultry demand by fearful consumers. Are there cost-effective and evidence-based measures that both reduce disease risk and protect the livelihoods of the smallholder farmers who account for most poultry production in Ghana?

What is the model innovation? The author develops a SAM for Ghana for 2005 that divides national production into four agroecological zones and 90 representative households classed by income and rural or urban location. The model is a recursive dynamic version of the IFPRI standard CGE model, which assumes the quasi-homothetic Stone-Geary utility function. Consumer aversion to chicken is simulated by reducing poultry meat's marginal budget share, a calibrated parameter in the Stone-Geary utility function. This results in a smaller increase in poultry meat demand for any given increase in income.

What is the experiment? The production effect of avian flu is modeled as a decline in the poultry sector's capital stock (which represents the culling of chickens) that reduces production by 10% for periods of one to three years, an outcome that is consistent with studies of this industry. Little is known of the virus's potential effects on consumer attitudes so the demand shock is described as a change in the marginal budget share parameter that reduces poultry demand by 40% from the baseline time path, for periods of one to three years.

What are the results? A decline in poultry production causes a shortage in poultry supply and tends to push producer prices upward. But the decline in consumer demand tends to cause producer prices to fall. Thus, model results show little change in poultry prices due to avian flu but much lower levels of both supply and demand.

gross complements. The CDE demand system also has the flexibility to specify different pair-wise substitution possibilities in models that include more than two commodities.

We illustrate the practical significance of the choice of utility function and parameter values by comparing the model results of the same experiment when making three different assumptions about consumer preferences. Our experiment is a 10% increase in the productivity of factors used in the production of services. This simulates an income increase in the U.S. economy and causes the price of services to fall relative to other goods. We use the GTAP model, which has a CDE demand system, for demonstration because we can

Table 4.4. *U.S. Private Household Default Demand Parameters in U.S. 3×3 Database*

	Income Parameter (INCPAR)	Substitution Parameter (SUBPAR)
Agriculture	0.17	0.82
Manufactures	0.88	0.20
Services	1.04	0.18

Source: GTAP v.8.1 U.S. 3×3 database.

choose CDE parameter values that will transform the CDE function into CES and Cobb-Douglas utility functions. However, we cannot replicate the Stone-Geary utility function, because it includes parameters for subsistence spending that are not accounted for in the CDE demand system.

The CDE system allows the modeler to define income and substitution parameter values. These parameters are not exactly the same as income and compensated price elasticities of demand, but they are closely related to them.[4,5] The CDE parameter values for the United States in our 3×3 database are reported in Table 4.4. The INCPAR income parameter values for the United States indicate that private household demand for services is relatively sensitive to income changes, but demand for agriculture (which is mainly foodstuffs) is not very sensitive to income changes. As the substitution parameter value becomes larger, the negative own-price and positive cross-price compensated elasticities become larger. Based on the SUBPAR parameter values, U.S. private households are relatively price sensitive with respect to their food purchases but less so with respect to purchases of services and manufactures.

We first carry out the model experiment using the CDE demand system. Then, we redefine income parameters and substitution parameters to correspond with a CES utility function (with a low, 0.5 elasticity of commodity substitution) and rerun the model experiment.[6] We take similar steps to define a Cobb-Douglas utility function.

4 A compensated own-price elasticity describes the consumer's demand response to a price change net of the income effect; it is the movement along an indifference curve.

5 Formulae that describe the relationship between the GTAP model's income parameter (INCPAR) and substitution (SUBPAR) parameters and income, own-price, and cross-price elasticities are derived by Hanoch (1975). For a detailed discussion of the CDE demand system, see McDougall (2003), Surry (1993), and Hertel et al. (1991).

6 To describe a CES function, we redefine CDE utility function income parameters for all commodities and regions to be 1 and define all substitution parameters to be 0.5, which describes a relatively low elasticity of substitution and a highly convex indifference curve. To describe a Cobb-Douglas utility function, we define all income parameters as 1 and all substitution parameters as zero. See Hertel et al. (1991b).

Table 4.5. *Effects of a 10% Increase in Total Factor Productivity in the Services Sector on Private Household Demand Assuming Different Consumer Preferences (% Change From Base)*

	Consumer Price (*pp*)	Consumer Demand Quantity (*qp*)	Expenditure on Commodity	Budget Share
Constant Difference of Elasticities (CDE)				
Agriculture	0.59	1.96	2.55	−2.06
Manufacturing	−0.20	5.46	5.26	0.52
Services	−5.07	9.66	4.59	−0.12
Constant Elasticity of Substitution (CES)				
Agriculture	0.91	6.22	7.13	2.41
Manufacturing	−0.24	6.80	6.55	1.86
Services	−5.19	9.27	4.08	−0.50
Cobb-Douglas				
Agriculture	0.64	4.10	4.74	0.00
Manufacturing	−0.18	4.92	4.74	0.00
Services	−5.05	9.78	4.74	0.00

Note: We use the Johansen solution method.
Source: GTAP model, GTAP v.8.1 U.S. 3×3 database.

In all three model experiments, national income increases by about 5%, which suggests that income effects on the commodity composition of demand may be important. Model results are reported in Table 4.5. In all three cases, the consumer price of services falls substantially relative to the prices of agricultural and manufactured goods. However, the effect on the consumer basket differs in the three cases, reflecting different assumptions about consumer preferences.

With the CDE function, income growth favors a disproportionate increase in quantity demanded for services, a luxury good, relative to the quantity of agricultural goods demanded. This income effect on demand reinforces the substitution effect on consumption, in which the increase in the consumer price for agriculture relative to services encourages a shift toward service consumption. Despite the shift in consumption toward services, its budget share declines slightly because more services can be purchased at a lower total cost. The budget share of agriculture falls because of its shrinking role in the consumer basket.

With the homothetic CES function, the 5% increase in income leads to a more equi-proportionate increase in the quantity demanded for all three commodities, and therefore a more evenly balanced growth within the basket compared to the CDE case. The homothetic income effect helps sustain demand for agriculture, despite the increase in its price relative to the other goods. With CES preferences, therefore, the budget share of the agricultural good increases instead of falling as in the CDE case. Still, as in the CDE case, the price effect causes consumers to substitute toward the consumption of services. The net effect is an increase in budget shares for agriculture and manufactured goods while the budget share of services declines.

In the case of the Cobb-Douglas function, budget shares are fixed by assumption so the price effect on quantity demanded is the inverse of the change in price. In agriculture, for example, the price increases by 0.64%, so the price effect on quantity demanded is –0.64%. The utility function's unitary income elasticity causes the quantities demanded for each good to change by the same proportion as the percent change in income, which is 4.74% in this experiment. On net, the change in consumer demand is the sum of the price and the income effect, or $-0.64 + 4.74 = 4.10\%$ in the case of U.S. agriculture.

The zero change in the agricultural budget share in Cobb-Douglas experiment contrasts with its decline in the CDE case and its expansion in the CES case, and illustrates the potential importance of these assumptions for your analysis. The right utility function for any specific analysis will depend on the research question and the flexibility offered by the CGE model to specify the utility function and the elasticity parameter values that best describe the economy under study. In general, homothetic functions are appropriate when income changes are small, as in our example, but nonhomothetic functions are better suited for shocks in which income changes are relatively large.

Import Demand

The second stage of the consumer's decision making determines the sourcing of each composite commodity. How much of the demand for a commodity will be met by the domestically produced variety and how much will be imported? In most CGE models, the allocation between domestic and imported goods reflects the assumption that the two varieties are imperfect substitutes. For example, Chilean consumers may feel that imported Chinese apples differ in flavor and texture from local apples. Chinese apples may be more suitable for baking in pies, while the Chilean variety is best eaten raw. These preferences would explain why there is two-way trade in apples between Chile and China and why the prices of the two types of apples may differ. Many CGE models describe these preferences using an *Armington import aggregation function*. The function describes how imported and domestic apple varieties are combined to produce the composite commodity, "apples," that is demanded by Chilean consumers.

The aggregation function can be drawn as an *isoquant*, shown as curve Q^1 in Figure 4.6. The isoquant is similar to an indifference curve in many

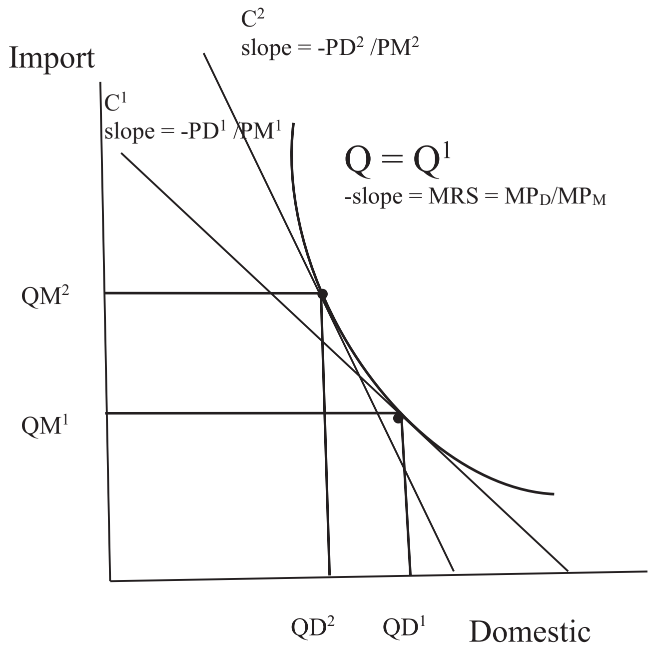


Figure 4.6. Armington aggregation function.

respects. It describes all possible quantity combinations of the imported and the domestic varieties that produce the same level of output of Q, the composite commodity. The further the isoquant lies from the origin, the larger is the quantity of Q that it represents. The negative of its slope at any point describes the MRS, which measures the quantity of imports, QM, that can be exchanged for a one-unit increase in the quantity of the domestic good, QD, holding Q constant. We can also express the MRS as the ratio of the *marginal product* of each variety in the production of Q, MP_D/MP_M.[7] The marginal product is the contribution to output of an additional unit of either input, holding the other input quantity constant. As the consumer moves down the isoquant, and production of Q becomes more intensive in the use of QD, the marginal product of QD falls relative to the marginal product of QM. For example, when the consumption basket is composed mostly of Chilean apples, the addition of yet one more eating apple is not as useful to the consumer as the addition of a Chinese baking apple.

The *import-domestic (Armington) substitution elasticity*, σ^D, describes the curvature of the isoquant. The smaller is σ^D, the less substitutable are QM

[7] The MRS is equivalent to the ratio of marginal products (MP_D/MP_M) because the slope at any point on the isoquant is $-dQM/dQD$, and since the marginal product of QD is dQ/dQD and of QM is dQ/dQM, the ratio $MP_D/MP_M = (dQ/dQD)/(dQ/dQM) = dQM/dQD$, which is the negative of the slope of the isoquant, or the MRS.

and QD in the production of Q and the more curved is the isoquant. Each additional unit of QD relative to QM causes a relatively large decline in the ratio PD/PM. Relative price changes must therefore be quite large to motivate consumers to give up imports for an additional unit of the domestic variety. In the limit, when the import substitution elasticity has a value of zero, the isoquant has the L-shape of a "Leontief" function, and QM will not be substituted for an additional unit of QD, regardless of any change in their relative prices. When the varieties are good substitutes, and σ^D is large, then the isoquant is relatively flat, showing that imports are easily substituted for the domestic variety, with little effect on the ratios of their marginal products in the production of Q. As the parameter value approaches infinity, the isoquant becomes linear and the two varieties become perfect substitutes.

C^1 is an *isocost* line with a slope of $-PD^1/PM^1$, where PD is the consumer price of the domestic good and PM is the consumer price of the imported good. The isocost line shows all combinations of the two goods that cost the same amount. Isocost lines that lie further from the origin represent higher costs. C^2 is a second isocost line, depicting price ratio PD^2/PM^2.

The consumer minimizes the cost of Q by choosing the quantities of imports and domestic goods described by the tangency between the isoquant and the lowest achievable isocost line. In the initial equilibrium shown in Figure 4.6, the consumer chooses quantities QM^1 and QD^1 at a cost of C^1. At the tangency, the ratios $MP_D/MP_M = PD^1/PM^1$. Rearranging (by multiplying both sides by MP_M/PD^1), $MP_D/PD^1 = MP_M/PM^1$. This means that costs are minimized when an additional dollar spent on the domestic or imported variety yields the same additional quantity of the composite good, Q. Suppose that the price of imports declines relative to the price of the domestic variety, as shown by the isocost line C^2. The least-cost ratio of input quantities shifts to QM^2/QD^2. The magnitude of the change in the quantity ratio, QM/QD, relative to the change in the price ratio, PD/PM, is determined by the isoquant's curvature as described by the import substitution elasticity parameter.

We explore the behavior of the Armington aggregation function in a CGE model by running an experiment that increases the price of imports relative to domestic goods while assuming different import substitution parameter values. We use the GTAP model and the U.S. 3×3 database to examine the effects of an increase in the U.S. import tariff on manufactured imports from the rest of the world. The results, reported in Table 4.6, show that when the goods are relatively poor substitutes, with an import substitution elasticity of 0.8, the quantity ratio of imports to domestic goods in the consumption of manufactures falls 4.6%. When goods are assumed to be readily substitutable, with a parameter value of 4, the quantity response is much larger – the ratio of imports to domestic goods declines by almost 18%.

Table 4.6. *Effects of an Increase in the U.S. Import Tariff on Manufactures to 10% on the Import/Domestic Quantity Consumption Ratio with Different Armington Elasticity Values (% Change from Base)*

	Import-Domestic Substitution Elasticity for Manufacturing		
U.S. Manufactures	0.8	1.2	4.0
Import quantity (*qiw*)	−4.1	−5.3	−13.7
Domestic quantity (*qds*)	0.5	1.0	4.1
Import/domestic quantity ratio (*qiw-qds*)	−4.6	−6.36	−17.9

Note: Elasticity of import substitution among import sources defined as the elasticity between domestic and imports multiplied by 2.
Source: GTAP model, GTAP v.8.1 U.S. 3×3 database.

As you might imagine, the sizes of import substitution elasticities are an important consideration for CGE modelers who study the effects of price changes, such as tariff reforms, on international trade. Indeed, these elasticities have received much attention in the CGE-based literature on trade policy because of the potential sensitivity of model results to the assumed parameter values. Modelers try to address these concerns by careful selection or estimation of their parameters and by testing the sensitivity of model results to their elasticity assumptions – subjects discussed in more detail in Chapter 3.[8]

Export Demand

Export demand is the demand by foreign consumers for the home country's exports. The treatment of foreign demand in a CGE model depends on whether the model is a multi-country model or a single-country model.

The multi-country case is straightforward: The demand for exports from country X by country Y is simply the demand for imports by country Y from country X. This is the case even when the global economy is aggregated into two regions, for example, the United States and rest-of-world, as in the model we use for demonstration. The slope of the foreign demand curve for a country's export good therefore depends in part on the foreign country's Armington import substitution elasticity. The larger its value, the more

[8] Discussion and critiques of Armington import substitution elasticities include Hillberry and Hummels (2013); McDaniel and Balistreri (2003); Erkel-Rousse and Mirza (2002); Gallaway, McDaniel, and Rivera (2000); Hummels (1999); Brown (1987); and Shiells, Stern, and Deardorff (1986). See Reinert and Roland-Holst (1992); Shiells and Reinert (1993), and Hertel et al. (2004a) for examples of studies in which CGE modelers estimated the Armington import demand elasticities used in their models.

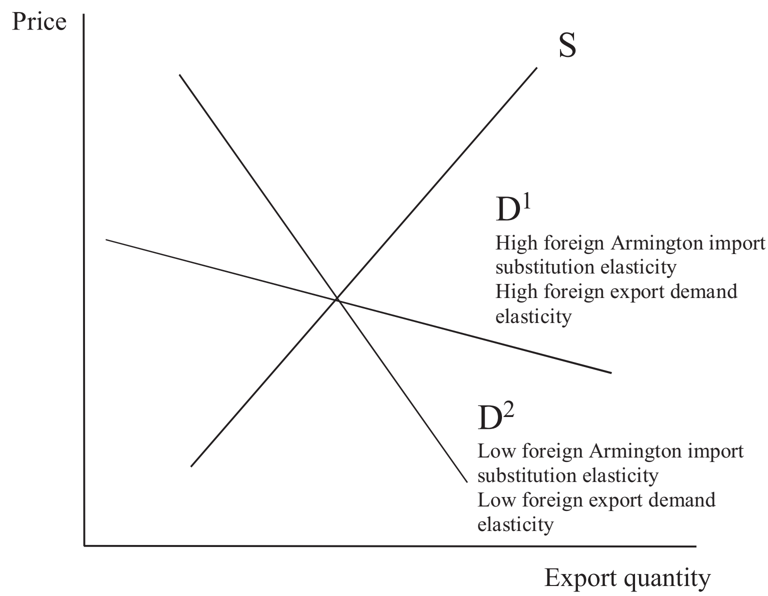


Figure 4.7. Elasticity parameters and the export demand curve.

elastic its import demand and therefore the more elastic the exporter's export demand curve.

Figure 4.7 illustrates the effect of foreign Armington elasticity parameters on a country's export demand. In the figure, S is the home country's supply of exports, D^1 describes a relatively elastic export demand curve (high foreign import substitution parameter), and D^2 describes a relatively inelastic export demand curve (low foreign import substitution parameter). For example, foreign countries' import substitution elasticities for dry milk powder are likely to be very high, because all varieties are nearly identical. The United States' export demand curve for dry milk powder is therefore probably similar to demand curve D^1. In this case, even a small increase in the relative world export price of the U.S. variety can lead foreigners to make a large substitution toward their own domestic product. Conversely, a low foreign import substitution elasticity implies an inelastic export demand curve for U.S. dry milk powder.

Single country CGE models do not describe the foreign economy or foreign import substitution preferences. Instead, demand for the home country's export is usually described using a simple expression that describes its aggregate export of each good:

$$QE/QW = (PXW/PWE)^{\theta}$$

where QE is the country's export quantity and QW is global trade in that good, so QE/QW is the country's market share in world trade. PXW is the world price and PWE is the *fob* world export price of the home country's export variety. Given the assumption that goods are differentiated by country of origin, a country's world export price can differ from the prices of its competitors. For example, the U.S. world export price for its corn, a yellow type used mainly for animal feed, can differ from the world export price of Mexico's corn, a white variety used mainly for food.

In the single-country model, a country can be assumed to be either *small* or *large* in its world export market by selecting the appropriate *export demand elasticity*, denoted by θ. This parameter measures the percent change in a country's market share given a percent change in the ratio of the global price to its world export price. When a country is small, it is reasonable to assume that any change in its export quantity is too small to affect the global price level. PXW remains fixed and the export demand elasticity approaches infinity. Any change in the country's world export price relative to the world price therefore results in large changes in export quantity and market share, so its foreign demand curve is relatively flat, similar to D^1. For example, if Uganda raises the price of its textile exports, it will not affect the world price level, but it is likely to cost Uganda a large portion of its market share in the world textile trade. Its output quantity will decline and, moving down its supply curve, its marginal costs will fall until Uganda's export price is again equal to the prevailing world price.

When the single country is assumed to be large in world markets, then its world export price can affect the world price level and its foreign demand elasticity is assumed to be low. In this case, a change in the exporter's world price relative to the average world price causes only a small change in its market share. For example, suppose that a drought reduces the export supply of white corn from Mexico, one of the world's major suppliers. This leads to an increase in its world export price and in the trade-weighted world price of white corn. The lower the foreign demand elasticity, the less willing are foreigners to change their quantity of corn imports from Mexico as its price rises, and the steeper is Mexico's downward sloping foreign demand curve.

Consumer Welfare

"Are you better off today than you were four years ago?" This was the famous question of the 1980 presidential campaign in the United States. How you can tell that you are better off? Economists answer this question by quantifying a "money metric" measure of the change in a nation's well-being, or welfare, following an economic shock. Such a measure has a cash value, such as $14 billion, that describes the welfare change in terms of an income equivalent. In this example, we could say that a nation's consumers are now just as well off as if they had been given an additional $14 billion to spend before an economic shock. Such a measure is useful because it allows us to make unambiguous comparisons of alternative polices or other shocks. For example, we can conclude that a policy that increases national welfare by $14 billion leaves us better off than one that increases our welfare by $5 billion. CGE models are particularly well-suited to quantifying welfare effects because they describe the effects of a shock on all prices and quantities in an economy. In fact, the measurement of welfare effects is one of the most important contributions that CGE models have made in empirical economic analysis.

In this section, we describe two approaches that are commonly used to measure welfare effects in standard CGE models that have a single, representative household. We start with the most intuitive, which is the money metric equivalent of changes in "real," or the quantity of, consumption of goods and services. A quantity-based measure has intuitive appeal because it is based on the idea that larger quantities of consumption make people better off. This welfare measure includes only changes in quantities, and not the value of consumption, because value changes might be due only to price changes. For example, if I buy one candy bar both before and after its price increases from $1 to $2, the value of my consumption has doubled but my real consumption has remained the same – one candy bar.

We calculate the *real consumption*, RC, welfare measure as the difference between the cost of the new basket, Q^2, and the cost of the initial basket, Q^1, valuing both baskets at the same, pre-shock consumer prices, P^1 for each good *i*:

$$\text{RC welfare } = \Sigma_{\text{i}} \left(P_{\text{i}}^{1} Q_{\text{i}}^{2}\right) - \Sigma_{\text{i}} \left(P_{\text{i}}^{1} Q_{\text{i}}^{1}\right)$$

Because the RC measure holds prices constant at their initial levels, a change in its value reflects only changes in quantities consumed. When the result is positive, real consumption has increased between periods one and two, and when the result is negative, real consumption has declined.

We can infer that an increase in real consumption is a welfare gain by drawing on the theory of revealed preference. At P^1 prices, the cost of Q^2 exceeded that of Q^1. Basket Q^2 was unaffordable and Q^1 was chosen. Following the shock, both Q^1 and Q^2 are affordable but Q^2 must be preferred because it is chosen. The cost difference between the baskets is equivalent to the additional income that the consumer would have needed to be able to afford the preferred basket, Q^2, at pre-shock prices.

All goods in the consumer basket are included in the welfare measure because a shock in one industry can affect prices and quantities throughout an economy. As an example, an import tariff reform may lower the consumer price of imported t-shirts. When the t-shirt price falls, you can either buy a larger quantity of t-shirts or, if you prefer, you can spend the money that you

Table 4.7. *Calculating the Real Consumption Measure of Welfare*

	Initial Price	Initial Quantity	New Quantity	Cost of Initial Quantity at Initial Prices	Cost of New Quantity at Initial Prices
T-shirts	$1.00	10	12	$10.00	$12.00
Books	$1.00	12	16	$12.00	$16.00
DVDs	$1.00	3	8	$3.00	$8.00
Total	–	–	–	$25.00	$36.00

have saved on t-shirts to buy more of other types of goods, such as books and DVDs. Therefore, the welfare measure must account for t-shirts, books, DVDs, and any other goods in your basket, even though the import tariff policy affects only t-shirts.

Table 4.7 illustrates how to calculate the real consumption welfare measure. Let's assume that we have used a three-good CGE model to analyze the effects of removing the import tariff on imported t-shirts. The original consumption basket is composed of ten t-shirts, twelve books and three DVDs. It costs a total of $25.00. The tariff removal causes all three consumer prices to change (these prices need not be reported). In this case, the removal of the t-shirt tariff enables the consumer to buy more of all three goods. At the original prices, the new consumption basket would have cost $36.00, or $11.00 more than the initial basket. There is a welfare gain of $11.00, which is equivalent to the additional income the consumer would have needed to purchase the new basket at the preshock prices.

Some CGE modelers take a different approach, and instead develop an *equivalent variation*, EV, welfare measure. It, too, is a money metric measure, but instead of comparing the cost of pre- and post-shock consumption quantities, it compares the cost of pre- and post-shock levels of consumer utility, both valued at base year prices. Because a CGE model contains a utility function, it is straightforward to calculate and compare the utility derived from different baskets of goods. For example, suppose the removal of the t-shirt tariff causes price changes that enable consumers to afford a new basket of goods that increases their utility from U^1 to U^2. The EV welfare effect measures the change in income that consumers would have needed to afford the new level of utility at preshock prices.[9] A positive EV welfare result indicates a welfare gain, and a negative result is a welfare loss.

[9] Compensating variation is an alternative utility-based measure of welfare that compares the cost of the new versus the old utility when both are valued in post-shock prices. Similarly, the real consumption measure of welfare can be calculated by comparing the costs of two baskets when both are valued in post-shock prices.

To demonstrate step by step how to calculate an EV measure of welfare, we use a two-good example of apples, QA, and oranges, QO. Let's assume that consumer preferences in our CGE model are described by a Cobb-Douglas utility function:

$$U = QA^{\alpha}QO^{1-\alpha}$$

where parameter α is the budget share for apples and, $1 - \alpha$, is the budget share for oranges. Our model will then specify the utility-maximizing demand functions for each commodity, which are derived from the utility function. In our example, the demand functions for any expenditure level, Y, and for any prices of apples, PA, and oranges, PO, are:

$$QA = \alpha(Y/PA)$$

$$QO = (1 - \alpha)(Y/PO)$$

If we assume that apples and oranges each account for a 50% budget share, expenditure in the base period is 100, and the initial price of apples is 4 and of oranges is 2, then the utility function is:

$$U = QA^{.5}QO^{.5}$$

and the utility maximizing quantities of apples and oranges are:

$$QA = .5(100/4) = 12.5$$

$$QO = .5(100/2) = 25.0$$

Now we are ready to run a model experiment. Let's assume that the economic shock has caused the apple price to fall to 2 but that the orange price and total expenditure remain unchanged. Based on our model's demand functions, we solve for the new, utility-maximizing quantities. Using these demand functions, verify that the quantity of apples demanded increases to 25 whereas the quantity of oranges demanded is still 25.

To calculate the equivalent variation welfare effect, our first step is to calculate the base level of utility, U^1, by substituting the base quantities for apples and oranges into the utility function:

$$U^1 = 12.5^{.5} * 25^{.5} = 17.7$$

Next, we calculate the new utility level, U^2, by substituting the new quantities into the utility function:

$$U^2 = 25^{.5} * 25^{.5} = 25.0$$

Then, we solve for the expenditure level required to achieve the new utility level at base prices by substituting the expressions for apple and orange quantities into the utility function, and solving for the total expenditure, Y.

Notice that our equation incorporates the new utility level (25) and the base year prices:

$$U^2 = 25.0 = [.5 * (Y/4)]^{.5} * [.5 * (Y/2)]^{.5}$$
$$Y = \$141.6$$

Last, we calculate the EV welfare measure, which is the change in expenditure that would have been required for consumers to afford the U^2 level of utility at pre-shock prices:

$$\$141.6 - \$100 = \$41.6.$$

For comparison, verify that the real consumption measure of welfare in this example is \$50.

The RC and the EV welfare measures are closely related. We illustrate this point in Figure 4.8, which describes and compares the results from our two-good example of apples and oranges. In the figure, the initial equilibrium is at point A on the U^1 indifference curve, given the initial price ratio between apples and oranges of P^1. The decline in the apple price is shown by the rotation of the price line to P^2. This causes the utility-maximizing consumer

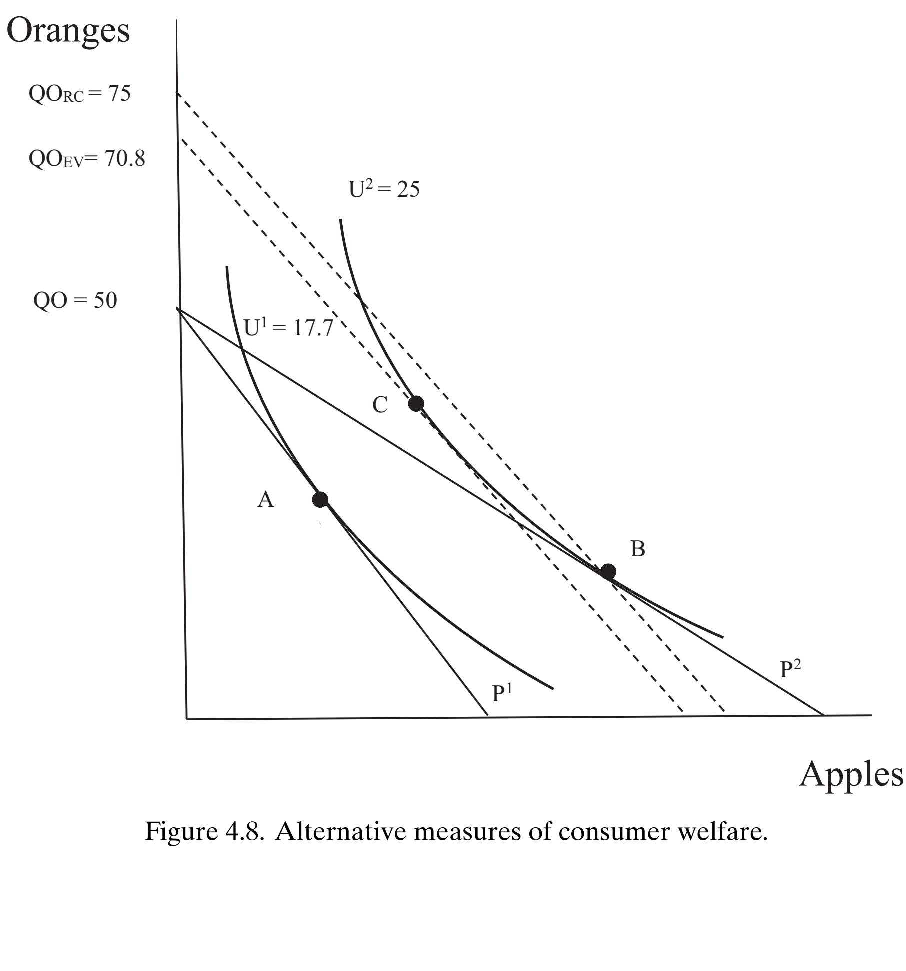


Figure 4.8. Alternative measures of consumer welfare.

to choose the consumption basket at point B, which provides a higher level of utility on the U^2 indifference curve. Using the real consumption measure, we can ask: "How much additional income would have been required to purchase the new basket, B, at the original prices?" The answer is shown as the vertical distance between the original budget line, P^1, and a budget line that is parallel to P^1 and goes through point B. Its intercept on the vertical axis at point QO_{RC} measures the total level of expenditure on basket B in terms of oranges, which is $2 * 75 oranges = $150.

Now suppose that, instead, we allowed the consumer to choose the least-cost basket of apples and oranges that generated the same U^2 level of utility as basket B, again at original prices. Given the consumer's preferences (shown by the curvature of the isoquant), that least cost bundle is at point C. Using the equivalent variation welfare measure, we can ask, "How much additional income would have been required to purchase a basket that yields the new utility level, U^2, at the original prices?" The answer is shown as the vertical distance between the original budget line and a budget line that is parallel to P^1 and goes through point C. Its vertical intercept at point QO_{EV} describes total expenditure on basket C in terms of oranges, which is $2 * 70.8 oranges = $141.60. In this case, if original prices had actually prevailed in period two, the consumer would have substituted between apples and oranges, spending less money on a basket, C, that was as satisfying as basket B.

The welfare measure that values the change in real consumption is the distance $QO - QO_{RC}$. It is 25 oranges, valued at $50. It exceeds the welfare measure that values the change in utility, shown by the distance $QO - QO_{EV}$, which is 20.8 oranges, or $41.60.

You may verify for yourself that as the elasticity of substitution becomes smaller, and indifference curve is more sharply curved, the distance between the EV and RC intercept becomes smaller. In fact, the two approaches yield identical results when the elasticity of substitution is zero, as in a Leontief fixed-proportion utility function, with L-shaped indifference curves.

CGE models can differ in their approaches to welfare measurement in other ways, too. For example, the GTAP model measures equivalent variation welfare effects on behalf of the regional household. It includes the combined changes in the utility of household consumers and government from their purchase of goods and services, and in addition includes domestic savings. Savings is included because it represents future consumption possibilities. In other CGE models, without a regional household, the welfare measure often describes only changes in quantities or utility from current consumption by private household consumers and may or may not also include investment spending. The modeler must then assume compatible macroclosure rules that fix the quantities purchased by government and perhaps of investors at their base levels.[10] It is well worth your time to study and understand the welfare measure used in your model, particularly so because this important summary measure is often presented as the "bottom line" of CGE-based analyses.

Summary

Final demand is the demand for goods and services for end use by private households, government, investors, and foreign markets. Data in the row accounts of the SAM describe the sources of income for each domestic agent and investment in the CGE model. Data in the column accounts of the SAM describe how their income is spent on commodities, and report export sales to the foreign market.

CGE models describe consumer demand as a two-stage decision. In the first stage, consumers allocate their income across commodities to maximize their utility, or satisfaction, given their preferences, budgets, and prices. When income or prices change, consumers readjust their basket of commodities to again maximize their utility. We describe and compare four functional forms commonly used in CGE models to describe private households' preferences: Cobb-Douglas, Stone-Geary/LES, and CES utility functions and the CDE demand system. Most CGE models describe the first stage of government and investment demand very simply by assuming that they spend a fixed share of their budgets on each commodity (i.e., a Cobb-Douglas utility function). In the second stage of the consumption decision, consumers minimize the cost of their consumption basket by choosing between imported and domestic products. This allocation is described by an Armington import aggregation function. In this chapter, we also describe and compare export demand in multi-country and single-country models and introduce the concept of national welfare, demonstrating how to calculate real quantity and equivalent variation welfare measures.

Key Terms

Budget constraint
Budget share
Cobb-Douglas utility function
Constant Difference of Elasticities (CDE) Demand System
Constant elasticity of substitution (CES) utility function
Elasticity, (Armington) import substitution
Elasticity, export demand
Elasticity, commodity substitution in consumption

[10] See Lofgren et al. (2002) for a discussion of the links between welfare measures and model closure.

Equivalent variation measure of welfare
Final demand
Gross complements
Gross substitutes
Homothetic utility function
Import (Armington) aggregation function
Indifference curve
Isocost
Isoquant
Large country
Luxury good
Marginal product
Marginal rate of substitution
Marginal utility
Necessity good
Net substitutes
Nonhomothetic utility function
Quasi-homothetic utility function
Real consumption measure of welfare
Small country
Stone-Geary Linear Expenditure System
Two-stage demand
Utility function

PRACTICE AND REVIEW

1. Using data from the U.S. 3×3 SAM,
   a. Trace the sales of U.S.-produced agricultural goods in final demand:

      C ______________ I ______________ G ______________ E ______________

   b. Trace the sales of U.S.-produced services in final demand:

      C ______________ I ______________ G ______________ E ______________

2. Using data from the U.S. 3×3 SAM,
   a. Calculate the budget shares of U.S.-produced goods in households' private consumption expenditure (including sales taxes):

      Agric: ______________ Mfg: ______________ Serv: ______________

3. Explain the difference between a homothetic and a nonhomothetic utility function. If you are conducting a study of foreign aid inflows and economic growth in a developing country, explain some of the differences in model results that you might expect to see when using the two utility functions.
4. Using a graph of the Armington aggregation function, explain the role of the Armington import substitution elasticity in determining the quantities demanded for imports and domestic goods if the removal of a tariff causes the relative price

of the import to fall. Compare the outcome in a case with a high substitution parameter value and a low parameter value.

5. Calculate the real consumption welfare effect using the data in Table 4.8. Has welfare improved or declined as a result of the price changes?

Table 4.8. *Practice and Review Calculation of the Real Consumption Welfare Measure*

	Initial Price	Initial Quantity	New Quantity	Cost of Initial Quantity at Initial Prices	Cost of New Quantity at Initial Prices
Agriculture	\$1.00	5	6		
Manufacturing	\$1.00	5	4		
Services	\$1.00	2	8		
Total	–	–	–		

Technical Appendix 4.1: Elasticity Parameters in Utility Functions

Table 4.9 describes the elasticity parameters that are required for four functional forms commonly used in CGE models to describe private households' preferences. The table describes the restrictions usually placed on the elasticity parameter values to ensure that the CGE model can be solved for a unique solution. The table also includes a brief explanation of different parameter values.

Table 4.9. *Elasticity Parameter Values in Utility Functions Commonly Used in CGE Models*

	Modeler Input	Parameter Restrictions	Parameter Values
Cobb-Douglas	None	None	Unitary (negative) own-price; zero cross-price, and unitary substitution and income elasticities are implied by the utility function.
Stone-Geary/Linear Expenditure System (LES)	Frisch parameter (ratio of total expenditure to discretionary expenditure)	$-1 \leq$ Frisch $\leq \infty$	All expenditure is discretionary: Frisch $= -1$ All expenditure is on subsistence requirements: Frisch $= \infty$
	Expenditure elasticity by commodity (E_i).	$0 \leq E_i \leq \infty$	Luxury goods: $E_i < 1$ Necessity goods: $0 \leq E_i < 1$
	Stone-Geary/LES collapses to a Cobb-Douglas utility function when Frisch $= -1$ and all $E_i = 1$.		
Constant Elasticity of Substitution (CES)	Elasticity of substitution by commodity (σ_i)	$0 \leq \sigma_i \leq \infty$	Leontief complements: $\sigma_i = 0$ Perfect substitutes: $\sigma_i = \infty$
	CES collapses to a Cobb-Douglas utility function when all $\sigma_i = 1$; and to a Leontief utility function when all $\sigma_i = 0$.		
Constant Difference of Elasticities (CDE)	$INCPAR_i$ – a parameter related to the income elasticity of demand for good i.	$0 < INCPAR_i$	Larger $INCPAR_i$ parameter value implies larger income elasticity of demand. Income insensitive (necessity) goods: $0 < INCPAR_i < 1$ Income sensitive (luxury) goods: $1 < INCPAR_i$ Homothetic demand: $INCPAR_i = 0$ for all *i*
	$SUBPAR_i$ – a parameter related to the compensated own and cross-price elasticities of substitution, defined for good i.	Either $SUBPAR_i < 0$ or $0 < SUBPAR_i < 1$ for all *i*	Larger $SUBPAR_i$ parameter value implies larger (absolute value) of compensated own-price elasticity. Leontief complements: SUBPAR $= 1$ for all i. Goods become substitutes as $SUBPAR_i$ and $SUBPAR_j$ become smaller. Independent goods: SUBPAR $= 0$ for all i.
	CDE collapses to a Cobb-Douglas utility function when all $INCPAR_i = 1$ and $SUBPAR_i = 0$; to a Leontief utility function when $INCPAR_i = 1$ and $SUBPAR_i, = 1$; and to a CES utility function when all $INCPAR_i = 1$ and SUBPAR are identical for all i.		

5

Supply in a CGE Model

In this chapter, we examine the supply side of an economy as represented in computable general equilibrium (CGE) models. The production data in the social accounting matrix (SAM) depict the production process, in which firms combine intermediate inputs with factors of production to produce goods and services. We use these data to calculate input-output coefficients, which describe the input intensity of production processes. CGE models break down the production technology into parts, depicting how subprocesses are nested within the overall production process. Within each nest, behavioral equations describe producers' efficiency-maximizing input demands and output levels, subject to their production technology. Export transformation functions, used in some CGE models, describe the allocation of production between domestic and export markets.

In 2009, the U.S. government offered financial assistance to its auto manufacturers to help them survive a deep recession and a free fall in consumer demand for cars. The bailout was controversial in part because the government seemed to be choosing to support a particular manufacturing industry. The government response was that the aid package not only helped save the jobs of autoworkers but also preserved jobs in the many industries that supply parts to the automakers and that sell and service autos. This part of the U.S. economic stimulus program built on the idea that an injection of support into one part of the economy would move in a circular flow to the rest of the economy, starting with the strong inter-industry linkages between automakers and the other manufacturing and service sectors that supply its inputs.

In this chapter and the next, we explore the supply side of the economy as represented in a CGE model, emphasizing the linkages among industries through their demands for intermediate inputs and their competition for the factors of production. We start with an examination of the production data in the SAM. The activity column accounts of the SAM describe the inputs used in industries' production processes. An activity's column is therefore much like a recipe because its lists all of the ingredients and the proportions used in making its product. Activity row accounts describe the use of industries' outputs as inputs for other industries. In the CGE model, producers are assumed to maximize their efficiency, subject to the technological requirements of their physical production process, as they choose inputs and their levels of output. We describe technologies and producer behavior in detail in this chapter and conclude by describing how producers are assumed, in some CGE models, to allocate their output between domestic and export sales.

Production Data in a SAM

Production activities use inputs to produce goods and services. Inputs are of two types: *intermediate inputs* (such as electronic components for a television or computer) and the *primary factor inputs* (land, labor, and capital) that are necessary to turn these intermediate inputs into final products. The activity columns in a SAM report the value of all intermediate and factor inputs and any taxes paid (or subsidies received) in the production of industry output.

To illustrate, Table 5.1 presents the three production activity columns from the U.S. 3×3 SAM (omitting the rows with zeros). Each column of the table shows the expenditure by that industry on all of its intermediate and factor inputs and on taxes. According to Table 5.1, U.S. agricultural producers spend \$194 billion on intermediate inputs. These are composed of \$36 billion of agricultural commodities (\$1 billion are imported and \$35 billion are produced domestically), \$71 billion of imported and domestic manufactured inputs, and \$87 billion of imported and domestic services. Notice that the table also shows how each type of good is used as an input into the other industries. The production of services, for example, requires substantial amounts of manufactured inputs.

In addition to intermediate inputs, U.S. agricultural production requires \$136 billion of factor inputs, which include \$36 billion for land, \$47 billion for labor, and \$53 billion for capital services. On net, U.S. agricultural producers pay \$1 billion in taxes on their use of factors, which includes their receipt of \$3 billion in subsidies on land and capital use (which have negative factor use taxes). Agricultural producers received an additional \$5 billion in subsidies to purchase intermediate inputs (a negative sales tax). Finally, because production taxes change producers' costs, the activity column also reports the production taxes paid (or subsidies received) by an industry. In agriculture, producers pay \$1 billion in production taxes.

The contributions of factors (and including all tax and subsidies) to increasing the value of the industry's finished goods is called the industry's value-added. For example, farm labor adds value to the agricultural sector's raw intermediate inputs, such as seeds, by planting and tending the seeds until they become the final agricultural product. In U.S. agriculture, value-added

Table 5.1. *Production Inputs in the U.S. 3×3 SAM ($U.S. Billions)*

SAM entry	Activities: Agric.	Activities: Mfg.	Activities: Services	Definition	
Commodities – total	194	4,335	6,885	Intermediate inputs	
Agric. imports	1	15	5		
Mfg. imports	9	797	300		
Services – imports	1	22	236		
Agric. – domestic	35	165	21		
Mfg. – domestic	62	2,007	1,502		
Services – domestic	86	1,329	4,821		
Factors – total	136	2,010	9,643	Factor payments	Value-Added
Land	36	0	0		
Labor	47	1,361	6,797		
Capital	53	649	2,846		
Factor use taxes – total	1	226	1,116	Factor use taxes	
Land	−1	0	0		
Labor	4	205	1,023		
Capital	−2	21	93		
Sales tax	−5	19	58	Sales taxes	
Production tax	1	70	511	Production tax	
Total	326	6,657	18,212	Gross value of output	

Note: Sales taxes rows in the SAM are aggregated into a single sales tax row. Numbers may not add to sum total due to rounding.
Source: GTAP v.8.1 U.S. 3×3 database.

totals $133 billion (i.e., $136 + $1 – $5 + $1 = $133 billion). Value-added plus the $194 billion value of intermediate inputs equals the gross value of output of U.S. agriculture of $326 billion (adjusted for rounding).

Input-Output Coefficients

The data reported in the activity columns of the SAM can be used to calculate a useful descriptive statistic called an *input-output coefficient*. These coefficients describe the ratio of the quantities of intermediate and factor inputs per unit of output. They are calculated by dividing every cell of Table 5.1 by its column total – the gross value of output.[1] The calculation excludes any taxes paid on inputs.

[1] The SAM reports value data so the input-output coefficients are value shares. But recall from Chapter 2 that if we normalize the data by assuming that it reports quantities per dollar, then we can interpret our input-output coefficients as ratios of input and output quantities.

Table 5.2. *U.S. Input-Output Coefficients*

	Production Activities		
	Agric.	Mfg.	Services
Intermediate inputs			
Agric. – imports	0.004	0.002	0.000
Mfg. – imports	0.028	0.120	0.016
Services – imports	0.002	0.003	0.013
Agric. – domestic	0.108	0.025	0.001
Mfg. – domestic	0.192	0.301	0.082
Services – domestic	0.263	0.200	0.265
Factor Inputs			
Land	0.110	0.000	0.000
Labor	0.144	0.204	0.373
Capital	0.161	0.097	0.156

Source: GTAP v.8.1 U.S. 3×3 database.

In Table 5.2, we display the input-output coefficients based on the U.S. 3×3 SAM (omitting the tax rows of the SAM). For example, the input-output coefficients for the agriculture activity indicate that .028 units of imported manufactured inputs are required per unit of output, and .108 units of domestically produced agricultural inputs are required, and so on.

The input-output coefficients in an activity's column account allow us to describe the *intermediate input intensity* or *factor intensity* of a production activity. A sector is "intensive" in the intermediate and factor inputs whose input-output coefficients are highest. For example, U.S. agriculture is capital-intensive because it uses more units of capital per unit of output than of land or labor. This knowledge can be useful if we want to design experiments or predict and interpret model results. For example, what if the U.S. government asks us to identify and study input subsidies that would most benefit farmers? Based on our input-output table, we could choose to focus our study on subsidies to manufactures, services, or capital inputs, because these are the inputs in which agricultural production is relatively intensive.

We can also use input-output coefficients to make scale-neutral comparisons of input intensities across industries and countries. For example, we could compare the capital input-output ratio between U.S. agriculture, .161, and U.S. manufacturing, .097. We can conclude that production of U.S. agriculture is more capital intensive than that of manufacturing because it has a higher capital-output ratio. The comparison is scale neutral because we can make this observation without confusing it with the observation that manufacturing, a far larger sector in the U.S. economy, accounts for vastly more capital usage than does agriculture.

Input-output coefficients in addition describe linkages among industries through their demands for intermediate inputs. *Upstream* industries are the domestic production activities that produce goods that are used as inputs into other *downstream* industries – as if products flowed downstream on a river from a producer toward the industries that use them as inputs. Domestic auto parts suppliers, for example, are an upstream industry that produces parts used downstream by auto assembly industries. Based on the U.S. 3×3 SAM, services is the major upstream industry providing intermediate inputs into U.S. agricultural and services production.

In a CGE model, intermediate input linkages create a channel through which a shock in one industry can affect the rest of the economy. For example, consider a shock that lowers the price of domestically produced services. Given the input-output coefficients reported in Table 5.2, we can see that this shock will lower the input costs of all sectors in the U.S. economy, but particularly of services and agriculture, which use these services inputs most intensively relative to manufacturing.

These inter-industry linkages often play an important role in explaining the results of experiments in a CGE model. However, as we will demonstrate in this chapter, a CGE model accounts for additional aspects of intermediate demand that are also important to consider. These include the relative size of each sector in the economy, the potential for imports to supplant domestic products in meeting demand for intermediates, and the ability of producers to substitute toward cheaper intermediate inputs in their production process.

Producer Behavior in a CGE Model

Behavioral equations in a CGE model govern producers' decisions about their input quantities and levels of output. In some models, producers are assumed to be cost minimizers who choose the least-cost level of inputs for a given level of output, given input and product prices and technological feasibility. Other CGE models describe producers as profit maximizers who choose quantities of both inputs and output, given input and product prices and subject to technological feasibility. The two approaches are just two sides of the same coin; both describe producers as maximizing their efficiency. Our discussion in the following sections mostly describes a cost-minimizing producer.

In addition to maximizing their efficiency, other important assumptions about producers that are commonly made in standard CGE models are that markets are perfectly competitive. Individual producers cannot influence the market prices of outputs or inputs, and they sell their output at their cost of production, making zero profits (in the economic sense). Production is also assumed to exhibit constant returns to scale. Thus, an increase of the same proportions in all inputs leads to an increase in output of the same proportion.

Technology Tree and Nested Production Functions

Because a producer's economic decisions on input and output levels are constrained by the firm's physical production technology, let's first explore in some detail how technological processes are described in a standard CGE model, before we consider economic choices any further. Technology defines the physical production process by which intermediate inputs, such as rubber tires and engines, are transformed by machinery and workers into a final product, such as an auto. This physical relationship is depicted by a *production function*. CGE models typically separate the production function into parts. In a diagram, it looks a lot like an upside-down tree. The trunk of the *technology tree* describes the final assembly of a good or service. Each tree branch is a subprocess with its own production function, or technology. The branches are called *nested production functions* because these smaller production processes are "nested" within the larger process of producing the final product. The twigs describe every input into the production process; each sprouts from the subprocess in which it is nested.

Figure 5.1 shows a technology tree that is typical of those assumed in standard CGE models. Notice how the figure shows two levels of the

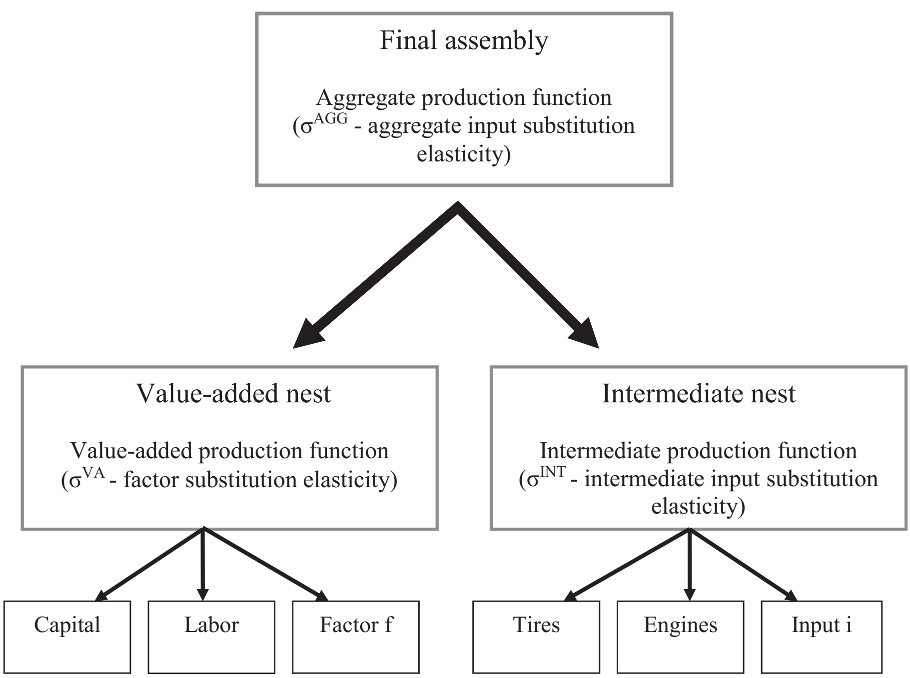


Figure 5.1. Technology tree for a nested production functions.

production process. At the bottom level are two nested production functions. One nest describes how the producer can combine labor and capital (and any other factors) into a value-added bundle that contains factor inputs. The second nest describes how intermediate inputs, such as tires and engines, are combined to form an intermediate bundle. Moving above, an aggregate production function describes how the producer combines the value-added bundle with the intermediate bundle to make the final product, such as an auto.

A nested production function is a useful approach when the technologies of the component processes are substantially different. For example, an automaker may find that it is easy to substitute between workers and mechanized assembly equipment within the value-added bundle but that it is difficult to substitute more tires for one less steering wheel within the intermediate bundle. Nested production functions allow the modeler to describe realistically the different ways that subsets of inputs are combined with each other during the production process.

An additional advantage of nesting is that the selection of input combinations within each nested process is independent of the contents of other nests. This assumption about their separability simplifies the database and the solution of a CGE model considerably. Instead of making pairwise decisions among all inputs, the producer is instead assumed to make one decision about the contents of the intermediate bundle, a separate decision about the contents of the value-added bundle, and another decision about the ratio of the intermediate and value-added bundles in the final product. Changing the ratios of inputs within the intermediate bundle will not influence the ratios of inputs within the value-added bundle. And, only three substitution elasticity parameters are required: one within each nest and one at the final assembly stage.

The specific type of production function, such as a Cobb-Douglas or Constant Elasticity of Substitution, that is assumed in each nest and for the final assembly, is determined by the modeler. A standard approach in CGE models is to assume functions that allow some substitution among factors of production in the value-added nest, but fixed input-output ratios in the intermediate nest and between the valued added and intermediate bundles. Later in this chapter, we describe in more detail the different types of production functions and their assumptions about input substitutability.

Sometimes, modelers choose to add additional nests to the production technology. CGE-based analyses of energy use and climate change, for example, usually add one or more levels of nesting to the value-added nest. Although the specific nesting structure varies across models, in general, these models include nests that describe the substitution possibilities between labor, capital, and a bundle of energy inputs. Additional nests then describe substitution possibilities among different types of energy within an energy bundle, such as coal, oil, or gas. An advantage of adding nests is that it allows the modeler to describe subsets of inputs as complements, instead of substitutes, within the production process. Technical Appendix 5.1 provides a more detailed discussion of nesting in CGE models focused on climate change mitigation.

Intermediate Input Demand

Now we are ready to study the producer's economic decisions, focusing on one nest at a time. We start with the demand for intermediates, which has the simplest technology. This is because CGE modelers usually assume that intermediate inputs are used in fixed proportions to produce the bundle of intermediate goods. This means that, for any given input bundle, the producer has no ability to substitute more of one intermediate input for another.[2]

For example, the production of an auto requires a bundle of intermediate inputs like rubber tires, engines, and mirrors. Furthermore, these inputs are ordinarily used in a fixed ratio. For each auto, the intermediate bundle must include four tires, one engine, and three mirrors. If the producer wishes to make another auto, he needs another bundle of auto parts – adding another wheel without an additional engine and so on would not increase the number of intermediate bundles. This technology is called a *Leontief fixed proportions production function*. It is named after Wassily Leontief, an economist well known for his work on inter-industry linkages in an economy. This type of intermediate production function offers a reasonable description of many intermediate production activities. Yet, it is a strong assumption. Changing it to allow producers some flexibility to substitute among inputs, such as coal and natural gas, has been one of the main advances made in CGE-based models focused on climate change (see Text Box 5.1).

A Leontief production function is depicted graphically as an L-shaped curve, QINT, in Figure 5.2. The curve is an *isoquant* that shows all combinations of two inputs – in this case, tires and engines – that can be used to produce a bundle of intermediate car parts of quantity $QINT^1$. The further an isoquant lies from the origin, the higher the number of intermediate bundles it represents. You can see from the isoquant's L-shape that increasing the amount of either tires or engines without increasing the quantity of the other input will not change the quantity of intermediate input bundles from level $QINT^1$.

[2] This treatment is widely used in CGE models. However, some models provide the modeler with the flexibility to define a nonzero elasticity of substitution between intermediate inputs. In this case, the technology in the intermediates nest is similar to that in the value-added nest, described in the next section.

Text Box 5.1. Climate Change, Emissions Taxes, and Trade in the CIM-EARTH Model

"Trade and Carbon Taxes" (Elliott et al., 2010b).

What is the research question? Climate change is a function of global CO_2 emissions, and the most efficient strategy to control them is to impose a uniform carbon tax wherever emissions occur. However, this approach presents a free-riding problem because nations have an incentive to not comply while gaining the benefits of reduced emissions elsewhere. How will carbon tax policies perform, given international trade, if countries adopt different carbon emissions tax rates?
What is the CGE model innovation? The researchers use CIM-EARTH, a recursive-dynamic, global CGE model with the GTAP v.7.0 database. The model places energy in the value-added nest and extends that nest to describe substitution possibilities among energy sources in the production of goods and services.
What is the model experiment? The authors define four scenarios: (1) the baseline time path is business as usual, with no carbon tax; (2) a carbon tax is applied uniformly across the globe; (3) a carbon tax is applied to emissions only in Kyoto Protocol Annex B countries (who have pledged to cut emissions); and (4) a carbon tax is applied to Annex B countries in combination with complete border tax adjustments that rebate their emissions taxes on exported goods and impose tariffs on emissions embodied in their imported goods. Carbon taxes in the last three scenarios range from \$4 to \$48 per ton of CO_2.
What are the key findings? A carbon tax applied worldwide at a uniform rate of \$48 per ton of CO_2 reduces emissions by 40% from 2020 levels. Increasing tax rates yield ever smaller reductions in emissions because the least-costly carbon-reducing steps are taken first. A carbon tax imposed only in Annex B countries generates little more than one-third of the emission reduction achieved with a uniform, global tax, due in part to substantial "carbon leakage" as production shifts to nontaxing countries. With full import and export border tax adjustments, carbon leakage is halted.

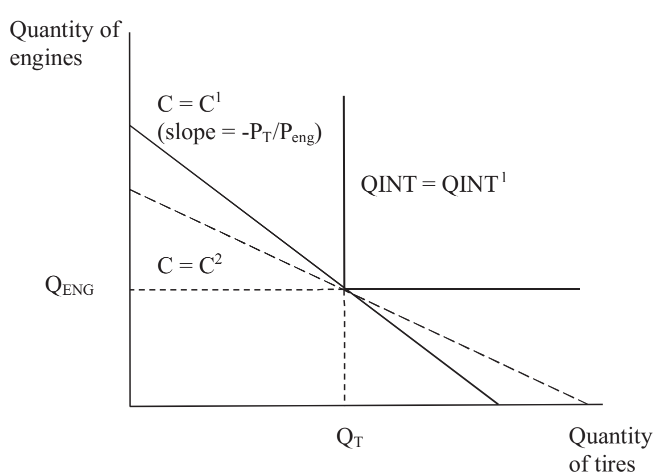


Figure 5.2. Nested production function – intermediate input demand.

The straight lines in Figure 5.2, C, are *isocost* lines. They show all combinations of engines and tires that cost the same total amount. The closer an isocost line lies to the origin, the lower is the total cost or outlay on tires and engines. The slope of an isocost line describes the ratio of input prices – in this case, the ratio of the tire price to the engine price, $-P_T/P_{ENG}$. The producer minimizes the cost of producing the input bundle $QINT^1$ when he operates at a point of tangency between the $QINT^1$ isoquant and the lowest attainable isocost line, which is C^1 in Figure 5.2, using the input bundle Q_{ENG} and Q_T.

The important property of a Leontief production function for CGE modelers to remember is that when relative input prices change, there is no change in the lowest-cost ratio of inputs for any level of QINT. Adding more of just one of the inputs would increase costs without increasing the number of intermediate bundles produced because the inputs must be used in fixed proportions. For example, assume that the price of tires falls relative to the price of engines, shown by the isocost line, C^2. The lowest-cost ratio of tires and engines remains unchanged. Because the ratio of input quantities does not change when input price ratios change, we say that the *elasticity of intermediate input substitution elasticity*, σ^{INT}, of a Leontief production function is zero.

We demonstrate how a Leontief intermediate production function determines input demands in a CGE model by carrying out an experiment that changes relative intermediate input prices. We use the GTAP model and the U.S. 3×3 database to run an experiment that imposes differing domestic sales tax rates of 5% on agricultural inputs, 10% on manufactured inputs, and 2% on services inputs. Results, reported in Table 5.3, demonstrate that when holding the intermediate bundle constant (i.e., we remain on isoquant $QINT^1$), there is no change in the quantities or ratios of intermediate inputs

Table 5.3. *Changes in Intermediate Input Demand When Relative Input Prices Change, with a Fixed Quantity of Intermediate Input Bundles (% Change from Base)*

	Production Activity		
Intermediate Input	Agriculture	Manufacturing	Services
Agriculture	0.00	0.00	0.00
Manufacturing	0.00	0.00	0.00
Services	0.00	0.00	0.00

Note: Because we assume that σ^{AGG} is zero, the change in demand for input i by activity j, remaining on the original isoquant, is approximately $qf_i - qo_j$.
Source: GTAP model, GTAP v.8.1 U.S. 3×3 database.

within the bundle as their relative prices change. Thus, given a Leontief technology, the original proportions remain the least-cost mix of intermediate inputs for a given level of intermediate input bundles. However, if the output quantity changes, say by 5%, then demand for each intermediate input will also change by the same proportion, 5%, leaving the intermediate input ratios unchanged.

Factor (Value-Added) Demand

CGE models specify a *valued-added production function* to describe the technology in the nest in which producers assemble their bundle of value added (i.e., the combination of labor, capital, and other factors used in the final assembly stage). Most CGE modelers assume that producers have some flexibility with regard to the factor composition of the value-added bundle. For example, although the assembly of an auto requires fixed proportions of four tires and one engine, the mix of capital and labor used to assemble the parts into an auto is somewhat variable. The assembly process can use a lot of manual labor and little machinery, or the process can be highly mechanized, depending on the relative cost of workers and equipment.

Figure 5.3 illustrates how producers choose the cost-minimizing factor ratio for a given quantity of value-added bundles. In the figure, an isoquant, QVA, describes the value-added production function. It depicts all technologically feasible combinations of two factors – capital, K, and labor, L – that can be used to produce the same value-added bundle, such as QVA^1. The negative of the slope at any point along the isoquant describes the marginal rate of

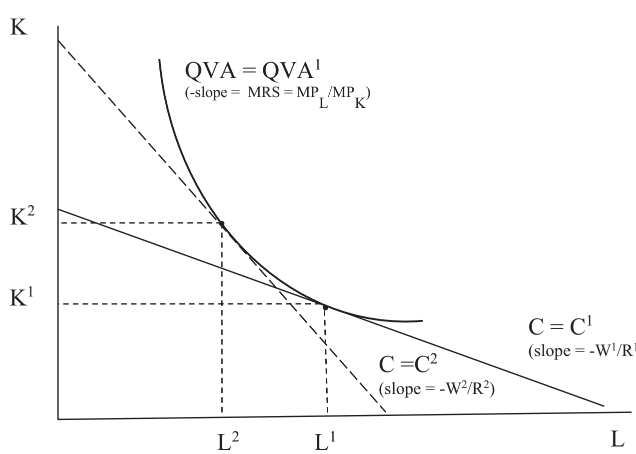


Figure 5.3. Nested production function – factor demand.

substitution (MRS) between the two inputs. The MRS measures the amount by which capital could be reduced if the quantity of labor is increased by one unit, while keeping output constant. We can also express the MRS as the ratio of the marginal product of labor to the marginal product of capital, or MP_L/MP_K in the production of QVA.[3]

To visualize these concepts, assume that the producer described in Figure 5.3 moves downward along the isoquant, using less capital and more labor in the production of the value-added bundle. Notice that as the ratio of capital to workers declines, a smaller quantity of capital can be substituted for each additional worker to produce the same QVA. As an example, assume that the automaker moves downward on its isoquant, employing more labor and using less assembly equipment. As an increasing number of workers shares fewer assembly tools, each additional worker becomes a less productive input to the value-added requirements of an auto, relative to an additional unit of equipment and tools. That is, as the K/L ratio falls, so does the inverse ratio of their marginal products, MP_L/MP_K.

The isocost line, such as C^1 in Figure 5.3, describes all combinations of labor and capital that can be purchased for the same total cost. Its slope depicts the relative wage and capital rent at initial factor prices, W^1/R^1. The producer minimizes the cost of producing QVA^1 at the tangency between the isoquant and the lowest achievable isocost line, C^1, using input ratio L^1/K^1. At their tangency, the ratio of marginal products is equal to the price ratio: $MP_L/MP_K = W^1R^1$. Rearranging (by multiplying both sides by MP_K/W^1) produces $MP_L/W^1 = MP_K/R^1$. Input costs are minimized for a given QVA when the marginal product from an additional dollar spent on labor is equal to the marginal product from an additional dollar spent on capital inputs. If not, producers will spend more on the more productive factor input and less on the other input, until their marginal products per dollar spent are equalized.

Now consider how the cost-minimizing factor input ratio changes if there is an increase in wages relative to capital rents. The rise in the wage-rental price ratio is shown in Figure 5.3 by the dotted isocost line, C^2, with slope $-W^2/R^2$. As workers become relatively expensive, the producer can reduce costs by substituting them with machinery. In Figure 5.3, inputs L^2 and K^2 become the cost-minimizing ratio of capital to labor in the production of QVA^1.

The *elasticity of factor substitution*, σ^{VA}, describes the relationship between changes in the capital-labor input ratio and the inverse ratio of their marginal products – that is, the curvature of the isoquant. When σ^{VA} is very large, the

[3] This is because, if d refers to a marginal change in quantity, then the slope at any point on the isoquant is $-dK/dL$, which is the rise over the run. Because the marginal product of L is $dQVA/dL$ and of K is $dQVA/dK$, then the ratio $MP_L/MP_K = (dQVA/dL)/(dQVA/dK) = dK/dL$, which equals the MRS.

technology is flexible, and the isoquant becomes flatter. In this case, even large changes in factor intensities have little effect on factors' marginal products. Producers can therefore make large shifts in their capital-labor ratios to take advantage of changing relative factor prices without experiencing a sizeable change in either input's marginal product. For example, if wages fall relative to rents, an automaker could hire more labor and use far fewer tools without causing labor productivity to decline relative to that of assembly equipment.

CGE modelers usually express σ^{VA} in terms of factors' prices instead of their marginal products, but the two concepts are equivalent. Parameter σ^{VA} is the percentage change in the quantity ratio of capital to labor given a percentage change in the wage relative to capital rents. In the limit, when σ^{VA} approaches infinity, factors are perfect substitutes in the production process, and the isoquant is a straight line. In this case, a decrease in one input can always be offset by a proportional increase in another input without affecting either input's marginal product. A change in relative factor prices will therefore lead to large changes in factor proportions. At the other extreme, a parameter value of zero describes a value-added isoquant with an L-shape. With this technology, capital and labor are Leontief complements that must be used in fixed proportions. A change in relative factor prices does not result in a change in the factor ratio. For most industries, substitutability is likely to be relatively limited. Reviews of the econometric literature on this parameter by Balistreri et al. (2003) and Koesler and Schymura (2012) found that the range of estimates clustered around values greater than zero but less than one.

CGE modelers are usually restricted to specifying one elasticity parameter for each industry that governs all pairwise substitutions among the factors of production in the model. Many CGE models use a constant elasticity of substitution (CES) valued-added production function to describe the value-added production technology, similar to the CES utility function studied in Chapter 4. It derives its name from the fact that the factor substitution elasticity remains constant throughout an isoquant (i.e., at any given factor input ratio). Reorder, and make this the first sentence of the paragraph.

The most important thing to remember about a value-added production function is that the ratio of factor input quantities can change when the relative prices of inputs change. Note, too, that if we allow substitution of one primary factor for another in the production process, the input-output coefficients for the factors, shown in Table 5.2, also change. This is not the case for the input-output coefficients for intermediate inputs when their ratios are assumed to be fixed (the "Leontief fixed proportions").

To illustrate these value-added concepts, we use the GTAP model and the U.S. 3×3 database to explore the effects on factor input ratios when the

Table 5.4. *Factor Substitution Effects of a Five-Percentage-Point Rate Increase in the Labor Tax in U.S. Manufacturing, with Different Factor Substitution Elasticities, Holding Output Constant (% Change from Base)*

	Manufacturing Activity	
	Capital/Labor Ratio	Wage/Rental Ratio
Elasticity of factor substitution = 1.2	2.81	3.56
Elasticity of factor substitution = 8.0	4.46	3.72

Notes: Percent change in the capital-labor ratio at constant output is approximately $(qfe_K - qo_{mfg})-(qfe_L - qo_{mfg})$. Percent change in the wage/rental ratio is approximately $(pfe_L - pfe_K)$.
Source: GTAP model, GTAP v.8.1 U.S. 3×3 database.

cost of labor increases relative to the cost of capital. Our experiment is a five-percentage-point increase, from about 15% to 20%, in the tax on labor employed in the U.S. manufacturing activity. We compare the effects of the tax when we assume a low factor substitution elasticity in manufacturing of 1.2 versus a large value 8, holding the quantity of value-added bundles constant (i.e., remaining on the same isoquant). You can visualize this experiment in Figure 5.3 by imagining that we are observing the producer substituting between the two inputs along (a) a highly curved isoquant in the case of the low substitution elasticity value, and (b) a flatter isoquant in the case of a high elasticity value. Our model results illustrate that the larger the elasticity parameter value, the larger is the producers' shift toward capital as the relative cost of labor costs rises (Table 5.4). Notice, too, that the increase in wages relative to rents does not differ much between the two cases. This is because, when production technology is more flexible, even a large increase in the capital-labor quantity ratio causes only a small change in the productivity (and price) of each input.

Combining Intermediate Inputs and Factors

At the top level of the assembly process, the producer combines the bundle of intermediate inputs with the bundle of factors to produce the final output. This aggregate technology is described by a production function in which the two bundles can be substituted according to an *elasticity of aggregate input substitution*, σ^{AGG}, similar to the value-added production function. In practice, this final stage of production is usually depicted as a Leontief fixed proportions technology, with σ^{AGG} assumed to equal zero. For any level of output, Q, a fixed ratio of intermediate and value added bundles is required. The addition of another bundle of intermediates without also adding a bundle of factors (or vice versa) will not increase output.

Text Box 5.2. Climate Variability and Productivity in Ethiopia

"Impacts of Considering Climate Variability on Investment Decisions in Ethiopia" (Block, Strzepek, Rosegrant, and Diao, 2006).

What is the research question? Extreme interannual rainfall variability that causes droughts and floods is common in Ethiopia. A model that describes climate using mean climate conditions (a deterministic model) does not capture the effects of year-to-year changes and extreme weather events. Would a stochastic model that incorporates both annual variability and the probabilities of extreme weather events result in different and more realistic estimates of production and climate effects on an economy?

What is the CGE model innovation? The authors develop annual climate-yield factors (CYF) by crop and agricultural zone within Ethiopia. The calculation of CYF's uses data on crop sensitivity to water shortages and 100 years of monthly rainfall data by zone. It also includes a flood factor, which decreases the CYF if the year is significantly wet or if the probability of flooding is high. CYF factors are used as multipliers of the technological productivity parameter in the production functions in the CGE model, which is an extension of the IFPRI standard CGE model.

What is the experiment? The 100 years of CYF data are divided into nine 12-year time periods from 1900 to 2000. The authors explore four time path scenarios for the 2003–2015 period: (1) a base scenario assumes historic, exogenous growth in endowments and productivity with no new policy initiatives; (2) an irrigation scenario adds to the base case the government's plans for expanded irrigation acreage; (3) an investment scenario adds to the base case a planned increase in government spending on infrastructure; and (4) a combined scenario assumes both irrigation and investment plans are realized. Model results are stochastic in the sense that all four scenarios are run assuming nine alternative weather patterns, producing an ensemble of outcomes.

What are the key findings? In the deterministic model, use of mean climate conditions is adequate when modeling drought, but this approach significantly overestimates the country's welfare when there are floods, which not only reduce agricultural yields but also lead to longer-term damage to roads and infrastructure and sustained losses in output.

Input Prices and Level of Output

Until now, we have explained how the cost-minimizing producer can (or cannot) substitute among inputs as their relative prices change to produce a given level of output, and we have remained on the same isoquant. However, in our general equilibrium framework, a change in input prices will usually lead to a change in output prices and in consumer demand. As a result, the level of output can change, too, whenever input prices change. The producer

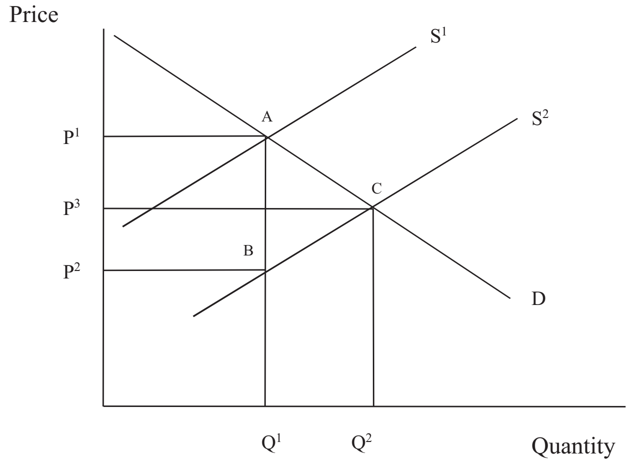


Figure 5.4. Input prices and level of output.

may shift to a higher output level, on an outer isoquant, or reduce his output, on an inner isoquant. These output changes will also affect the quantities of inputs required, although not their ratios.

First, let's consider in more detail how a change in the price of an input works through consumer demand in the CGE model to affect the level of output. Labor union concessions, for example, might lower wage costs for automakers. If their technology allows it, automakers will substitute more labor for less equipment in their production process at any given production level. The more that producers can substitute toward labor (i.e., the larger is the elasticity of factor substitution), the lower their production costs become. As production costs fall, then in perfectly competitive markets, so will auto prices. This point is illustrated in Figure 5.4. In the initial equilibrium, at point A, quantity Q^1 is demanded at price P^1. A reduction in the cost of an input is described by the downward shift in the supply curve from S^1 to S^2, with the same quantity of Q now produced at a lower price, P^2, and shown by point B. Depending on consumer preferences, the fall in the price of autos will stimulate consumer demand. In the new equilibrium, an increase in the quantity demanded causes output to increase to Q^2 quantity of autos at price P^3, at point C. This increase in output, in turn, leads to an increase in producer demand by the same proportion for all inputs. That is, a 10% increase in auto output will lead to a 10% increase in demand for both autoworkers and assembly equipment, as well as for all intermediate inputs.

In Figure 5.5, we show more specifically how the effects of a change in one input price – in this case, a fall in capital rent – on demand for both factor inputs can be decomposed into *substitution effects* and *output effects*.

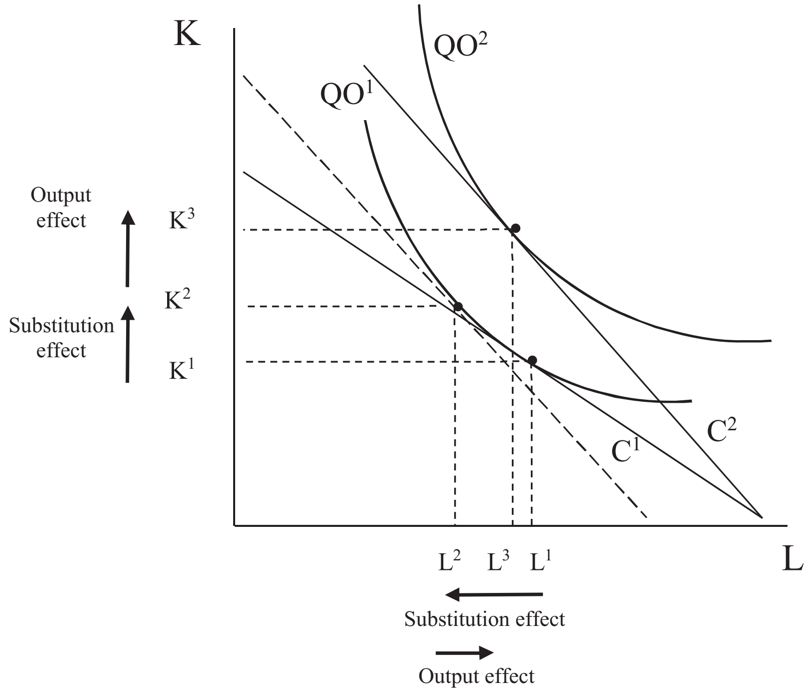


Figure 5.5. Input demand and output levels.

(The alert student will find similarities between this exposition and our discussion of income and substitution effects on consumer demand in Chapter 4.) In the figure, QO^1 is the initial level of output of QO, which is produced using the factor input ratio K^1/L^1. You may notice that we have drawn the figure to show K and L as inputs into QO, instead of QVA, the value-added bundle. This is possible because we assume that the top of the nest requires a fixed proportion of value-added bundles in the production of QO.

The slope of the isocost line, C^1, describes the initial ratio of wages to rents, W/R^1. A fall in the price of capital is shown as isocost line C^2, with slope $-W/R^2$. A decline in the cost of capital lowers the cost of production and leads to higher demand for the final product. Output increases to QO^2, using factor inputs quantities of K^3 and L^3.

To measure the substitution effect, imagine that producers continue to produce QO^1 but purchase inputs at the new price ratio, shown as the dotted line drawn parallel to isocost line C^2. The substitution effect measures the movement along the QO^1 isoquant to the tangency between the isoquant and the new isocost line. As the relative price of capital falls, more capital and less labor are used in the production of QO^1. This change in the factor ratio, from L^1 and K^1 to L^2 and K^2, is the substitution effect. The movement from L^2 and K^2 to L^3 and K^3 is the output effect. It measures the change in factor demand due to the change in production quantity from QO^1 to QO^2, holding the factor prices constant at the new price ratio. The expansion of output leads to a proportionate increase in demand for both inputs.

To explore these concepts in a CGE model, we use the GTAP model with the U.S. 3×3 SAM to run an experiment in which capital rents fall relative to wages. The experiment assumes a 10% increase in the U.S. capital stock, which reduces economy-wide capital rents by 6.8% and increases U.S. wages by 0.3%. The percentage rise in the wage/rental ratio is therefore 0.3 – (–6.8) = 7.1.

For brevity, we describe the results only for the U.S. services industry. The lower price of capital reduces the cost of the value-added bundle used in the production of services. In the new equilibrium, the consumer price of domestically produced services declines by 1.6%, private consumer demand for these services increases 1.9%, and their production rises 2.1%.

The effects on service's intermediate and factor inputs are reported in Table 5.5. The output effect increases demand for all intermediate and factor inputs by the same proportion as the change in services output – 2.1%. In the intermediate bundle, the substitution effects are zero because we assume a Leontief intermediate production technology with fixed input-output ratios. In the value-added bundle, the substitution effect results from an increase in the wage-rental ratio, which causes the production of services to become more capital intensive. In total, the combined substitution and output effects stimulate service's demand for capital. In the case of labor, the negative substitution effect on labor demand outweighs the positive output effect and results in a decline in services' demand for labor.

Table 5.5. *Effects of a Fall in the Price of Capital Relative to Labor on Input Demand in U.S. Services Industry (% Change from Base)*

Input	Substitution Effect	Output Effect	Total Input Demand
Intermediate inputs			
Agriculture	0.0	2.1	2.1
Manufacturing	0.0	2.1	2.1
Services	0.0	2.1	2.1
Factor inputs			
Capital	7.6	2.1	9.7
Labor	–2.7	2.1	–0.6

Notes: The experiment is a 10% increase in the U.S. capital stock. The substitution effect is approximately *qfe* – *qo*. The output effect is variable *qo* and demand for intermediates and for factor inputs are *qf* and *qfe*, respectively.
Source: GTAP model, GTAP v.8.1 U.S. 3×3 database.

Export Supply

In CGE models, an increase in price in the export market relative to that in the domestic market usually leads a producer to shift sales of his product toward exports, and vice versa. However, in some CGE models, output is described as a composite commodity composed of the variety that is exported and the variety that is sold domestically. The two varieties are assumed to be two different goods, and the producer may not be able to readily transform his product line between them. Perhaps electric clocks require different electrical plugs when used in different countries, or the production process for beef may need to meet different consumer safety standards in each market. CGE models in which goods are differentiated by destination markets include an *export transformation function* to describe the technological flexibility of producers to transform their product between export and domestic sales.[4]

We depict the function as a *product transformation curve*, shown in Figure 5.6. It shows all technologically possible combinations of the export, QE, and domestic, QD, varieties that can be produced from a given level of resources and that comprise the composite output quantity, QO. Perhaps QE and QD are European and American styles of the electric clocks, and QO is the total supply of electric clocks. The farther the transformation curve, QO, lies from the origin, the larger is the quantity of production of the composite QO.

The most obvious difference between this function and the value-added production function that we have already studied is that the export

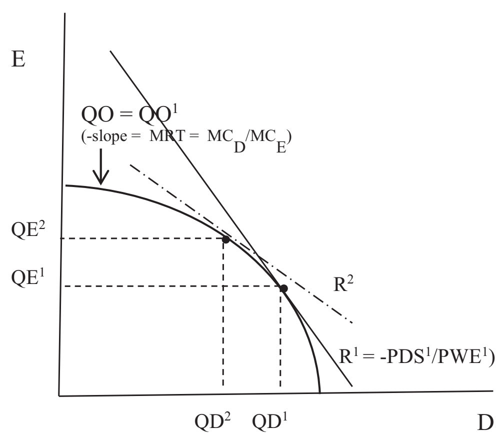


Figure 5.6. Export transformation function and a change in relative prices.

[4] Mainly GAMS-based CGE models include export transformation functions. An early example is the single-country Cameroon model developed by Condon et al. (1987). Others with this export treatment include the ERS-USDA CGE model (Robinson et al., 1990), the IFPRI standard model (Lofgren et al. 2002), the GLOBE model (McDonald et al., 2007), and the TUG-CGE model (Thierfelder, 2009).

transformation curve is drawn concave to the origin, while isoquants are convex. As we will show, its concave shape means that an increase in the price of QD or QE *increases* its use in the production of QO, whereas with the convex isoquant, an increase in an input price *decreases* its use.

The export transformation curve is otherwise similar in many respects to the value-added isoquant. The negative of its slope at any point describes the *marginal rate of transformation* (MRT), which measures the producer's ability to substitute QE for QD in the production of a given level of QO. We can also express the MRT as the ratio of the marginal costs of QD and QE in the production of QO, or MC_D/MC_E.

You can visualize why the two expressions for the curve's slope are equivalent by imagining a point on the curve in Figure 5.5 at which production is almost entirely specialized in exports. As the producer shifts toward domestic sales, the value of MRT becomes larger, because more units of QE must be given up for each additional unit of QD that is produced. This is because the inputs that are most productive when used in QD, and the least productive when used in QE, are the first to be shifted toward QD as its output increases. As output of QD expands further, it draws in less and less productive inputs and QE retains only its most productive inputs. Therefore, the marginal cost of producing QD rises and the marginal cost of producing QE falls as production shifts toward QD.

The line in the figure, R^1, with slope $-PDS^1/PWE^1$, is an *isorevenue* line, where PDS is the producer's sales price of the good in the domestic market and PWE is the *fob* export sales price. The isorevenue line shows all combinations of QE and QD that generate the same amount of producer revenue from the sale of QO. The further this line from the origin, the higher is producer revenue.

The producer's problem is to choose the ratio of export and domestic varieties for a given QO that maximizes his revenue – shown by the achievement of the highest attainable isorevenue line on any given product transformation curve. In Figure 5.6, revenue from output QO^1 is maximized at output ratio QE^1/QD^1. At this point, the transformation curve and the isorevenue line are tangent and $MC_D/MC_E = PDS^1/PWE^1$. Rearranging (by multiplying both sides by MC_E/PDS^1) revenue is maximized where $MC_D/PDS^1 = MC_E/PWE^1$. That is, each additional dollar of revenue from QE and QD incurs the same marginal cost. If not, producers will produce more of the variety whose marginal cost is lower, and less of the variety whose marginal cost is higher, relative to its price.

Assume that the relative price of exports increases, as shown by the dotted line R^2 in Figure 5.6. The revenue-maximizing producer will increase the ratio of exports to domestic sales in output QO^1, to ratio QE^2/QD^2. The size of this quantity response depends on the curvature of the transformation curve,

Table 5.6. *Effects of a 5% Increase in the World Export Price of U.S. Manufactured Exports on the Production of Exported and Domestic Varieties (% Change from Base)*

	Export Transformation Elasticity	
U.S. Manufacturing	–0.8	–4.0
Export/domestic production ratio	2.7	5.75
Total manufacturing output	0.1	0.6

Source: TUG-CGE (Thierfelder, 2009), GTAP v.8.1 U.S. 3×3 database.

which is defined by the *elasticity of export transformation*, σ^E. The parameter defines the percentage change in the quantity ratio of exports to domestic goods given a percentage change in the ratio of the domestic to the export sales price for a given level of output. If the varieties are perfect substitutes in the composition of QO, then the transformation parameter (always expressed as a negative value) has an absolute value that approaches minus infinity and the transformation curve becomes linear. In this case, a small change in the price ratio will result in a large change in the product mix. As the two products become less substitutable in the production of QO, the absolute value of σ^E approaches zero.

CGE models that describe export transformation generally assume a constant elasticity of transformation (CET) function to describe the producer's decision making.[5] The CET function derives its name from the fact that the export transformation elasticity is constant throughout the product transformation curve, and at any level of QO.

We illustrate the properties of an export transformation function in a CGE model by running an experiment that increases the world export price of U.S. manufactured goods by 5%. We use the U.S. 3×3 database in the TUG-CGE model, a single-country model developed by Thierfelder (2009) that contains a CET export transformation function.[6] We compare the effects of the price shock on the quantity ratio of exports to domestic goods using two different values of the export transformation elasticity parameter. As the parameter's absolute value becomes larger and the transformation technology becomes more flexible, a 5% increase in the world export price elicits a larger export supply response from U.S. manufacturers (Table 5.6). Notice, too, that total output increases more when producers are relatively flexible in

[5] See Powell and Gruen (1968) for a detailed presentation on the CET function.
[6] World export and import prices are assumed to be exogenous variables in this single-country CGE model.

shifting toward export opportunities. Because the inputs are relatively suitable for use in the production of either variety, the marginal cost of producing additional exports does not rise as fast as in the low-elasticity case.

Summary

In this chapter, we examined production data in the SAM and producer behavior in the CGE model. Data in the SAM describe each industry's production technology, reporting its use of intermediate and factor inputs and any taxes paid or subsidies received. We used the SAM's production data to calculate input-output coefficients that describe the units of intermediate and factor inputs required per unit of output. Input-output coefficients are useful for characterizing production activities' intermediate- and factor-intensities, comparing input intensities across industries, and describing inter-industry linkages from upstream to downstream industries.

CGE models use nested production functions. These break down the production technology into subprocesses that, when diagrammed, look like an upside-down tree. The trunk is the assembly of the final good, its branches are the subprocesses that are nested within the overall production process, and its twigs are the inputs used in each subprocess. Each subprocess and final assembly has its own production technology, cost minimization equation, and input substitution elasticity parameter. In the intermediates' nest, producers decide on the cost-minimizing levels of intermediate inputs, and in the value-added nest, producers choose the cost-minimizing levels of factor inputs. Some CGE models include export transformation functions, which describe how producers allocate their output between exports and sales in the domestic market.

Key Terms

Constant elasticity of substitution (CES) value added production function
Constant elasticity of transformation (CET) export supply function
Downstream industries
Elasticity of aggregate input substitution
Elasticity of export transformation
Elasticity of factor substitution
Elasticity of intermediate input substitition
Export transformation function
Factor intensity
Input-output coefficient
Intermediate input
Intermediate input intensity
Isocost

Isoquant
Isorevenue
Leontief fixed-proportion production function
Marginal rate of transformation
Nested production function
Output effect on factor demand
Primary factor inputs
Product transformation curve
Production function
Substitution effect on factor demand
Technology tree
Upstream industries
Value added
Value-added production function

PRACTICE AND REVIEW

1. Use the U.S. SAM (in Appendix A), to describe the production technology of the U.S. manufacturing sector:

   Total intermediate inputs ________________________________
   Total factor payments ___________________________________
   Total tax (and subsidy) __________________________________
   Value-added ____
   Gross value of output ___________________________________

2. Data in exercise Table 5.7 describe the inputs purchased by manufacturing and services for their production process. Calculate the input-output coefficients for the two industries and report them in the table. Answer the following questions:
   a. In which factor is the production of manufacturing most intensive?
   b. In which factor is the production of services most intensive?
   c. Which industry is more intensive in the use of services?
   d. Describe the upstream and downstream role of manufacturing.

Table 5.7. *Input-Output Coefficients Exercise*

	Inputs Into Production		Input-Output Coefficients	
	Manufacturing	Services	Mfg.	Services
Labor	12	12		
Capital	8	18		
Manufacturing	10	50		
Services	20	20		
Gross value of output	50	100		

3. Assume that you are CEO of a small firm. The introduction of a universal health insurance program has eliminated your health premium payments and lowered your cost per worker. Using a graph that describes your cost-minimizing choice of capital and labor shares in the value-added bundle, explain how the new program will change the labor-capital ratio in your production process, for a fixed level of value-added.
4. Consider the following results reported in Table 5.8, from a model with a nested production function. Can you infer from the results the percentage change in the industry's production, the possible types of production functions used in the each nest, and the likely change in relative factor prices that accounts for these results?

Table 5.8. *Effects of a Change in Factor Price on an Industry's Input Demand*

Input	Substitution Effect	Output Effect	% Change in Input Demand
Agriculture	0	3.5	3.5
Manufacturing	0	3.5	3.5
Services	0	3.5	3.5
Capital	–4	3.5	–0.5
Labor	6	3.5	9.5

Technical Appendix 5.1: Inputs as Substitutes or Complements – Energy Nesting in CGE Models of Climate Change Mitigation

The production functions used in CGE models describe inputs as substitutes or Leontief complements in the production process. However, in some cases, it may be more realistic to describe some inputs as true complements in the sense that an increase in one input price causes demand for the other input to fall. The presence of complementary inputs is especially important in the analysis of climate change mitigation. CGE modelers studying this subject typically examine whether there are cost-effective ways to encourage a substitution away from particularly dirty sources of energy to cleaner sources that have less of an environmental impact. Their analyses usually allow some degree of substitutability between capital and energy, yet characterize these two inputs as overall complements, at least in the short run. Capital-energy substitution assumptions are important because the estimated costs of reducing carbon emissions are lower the more flexible are production technologies.

CGE models used for climate change mitigation analysis usually move energy from the intermediate input bundle into the value-added (VA) nest. Some models, including the example we study in this appendix, combine capital (K) and energy (E) into a composite bundle, KE, that is combined

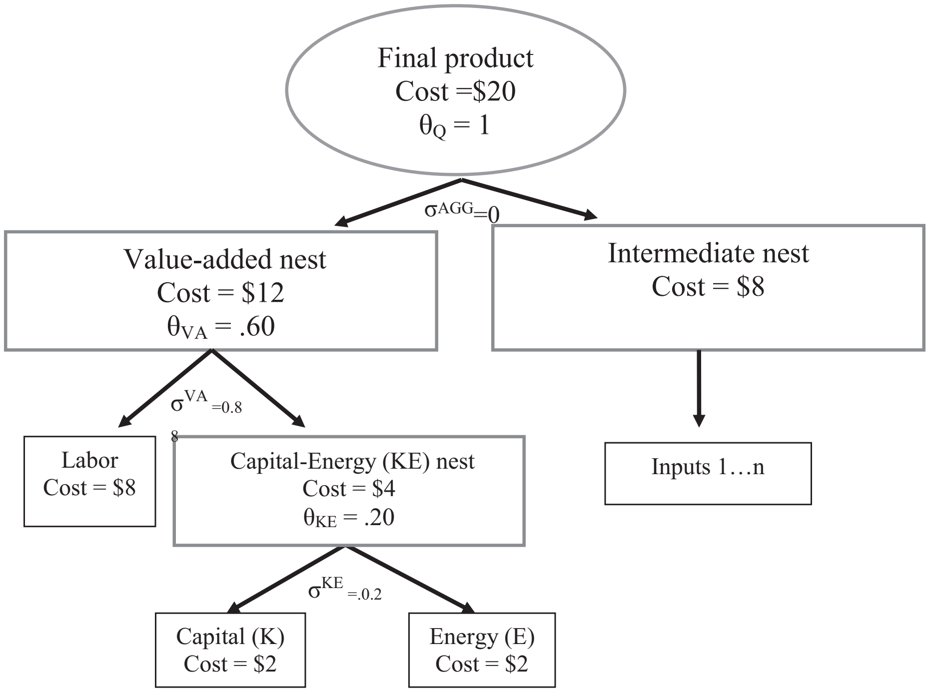


Figure 5.7. Technology tree with a KE-L nest.

with labor in the VA nest, as illustrated in Figure 5.7. The modeler then adds a nest to describe how capital and energy are combined to produce the KE bundle. Modelers also add additional nests to describe substitution among energy types which, for brevity, we do not discuss.

Adding a KE nest to the value-added production function is a technique that allows modelers to describe K and E as overall complements while still allowing for a realistic amount of substitution between them. For example, suppose the price of energy rises. Within the KE nest, the quantity of energy demanded will fall and demand for capital will rise, to the extent that capital equipment can be substituted for energy. However, substitutability within the KE nest is likely to be quite low, because, generally, machinery needs a certain amount of electricity to run properly. As a result, the price of the KE bundle likely rises and the producer will shift toward labor and away from the KE bundle in the higher-level, VA nest. As demand for the KE bundle falls, demand for both capital equipment and energy will fall by the same proportion. If the within-KE substitution effect dominates, then an increase in the energy price will cause demand for capital to rise – K and E are overall substitutes. If the VA substitution effect dominates, and the rise in the energy price causes demand for capital to fall, then K and E are overall complements.

Table 5.9. *Within-Nest and Overall Capital-Energy Substitution Parameters*

	Substitution Parameter			Share in Total Cost of Production			Overall K-E Substitution
	KE Nest (σ^{KE})	VA Nest (σ^{VA})	VA-Intermediate (top) Nest (σ^{AGG})	KE (θ_{KE})	VA (θ_{VA})	Q(θ_Q)	(σ^{KE^*})
Base case	0.2	0.8	0	0.2	0.6	1	–1.66
High KE cost share	0.2	0.8	0	0.5	0.6	1	0.13
High KE substitution	0.9	0.8	0	0.2	0.6	1	1.83

Note: Formula for overall K-E substitution is: $\sigma^{KE^*} = \sigma^{KE}(\theta_{KE}^{-1}) - \sigma^{VA}(\theta_{KE}^{-1} - \theta_{VA}^{-1}) - \sigma^{AGG}(\theta_{VA}^{-1} - \theta_{Q}^{-1})$.

Keller (1980) developed a formula to calculate the overall substitution parameter for nested inputs like capital and energy, σ^{KE^*}. His formula defines the parameter as a function of all three substitution effects – within the KE bundle, σ^{KE}; within the VA bundle, σ^{VA}; and at the top level of aggregation, σ^{AGG} – and of each nest's share in the total cost of the final product. Table 5.9 demonstrates how the overall substitution parameter is calculated, using the data shown in Figure 5.7.[7] In this example, the cost share of the KE bundle, θ_{KE}, is \$4/\$20 = 0.20, and the KE substitution parameter is 0.2. The cost share of the VA bundle, θ_{VA}, is \$12/\$20 = 0.6 and the L-KE substitution parameter is 0.8. The elasticity parameter, σ^{AGG}, between VA and intermediate inputs is zero. The cost share of the final product itself, θ_Q, is one.

Using Keller's formula, capital and energy inputs are overall complements, with an overall substitution elasticity parameter of –1.66. As illustrations, a change in the cost shares that gives more weight to the within-KE process causes its substitution effect to dominate, so capital and energy become overall substitutes, with a parameter value of .13. A change in relative elasticities, making capital and energy more substitutable in the KE nest, also causes the two inputs to become overall substitutes, with a parameter value of 1.83.

[7] For a more general statement of this formula for any number of nesting levels, see Keller (1980) and McDougall (2009).

6

Factors of Production in a CGE Model

In this chapter, we explore factor markets in a computable general equilibrium (CGE) model. Data in the Social Accounting Matrix (SAM) on factors of production describe factors' sources of employment and income. Important factor market concepts in the CGE model are factor mobility assumptions, the effects of factor endowment and productivity growth, complementary and substitute factors, full-employment versus unemployment model closures, and the links between changes in factor supply and industry structure and between changes in industry structure and factor prices.

Factors of production are the labor, capital, land, and other primary resources that producers combine with intermediate inputs to make goods and services. A nation's *factor endowment* is its fundamental stock of wealth because factors represent its supply of productive resources. In Chapter 5, we considered production activities' demand for factors and how these adjust with changes in relative factor prices or output levels. Many other dimensions of factor markets in a CGE model also deserve study.

In the next sections, we describe factor markets in standard CGE models in detail, focusing on those aspects that are of greatest practical importance for CGE modelers. We begin by studying the factor market data in the SAM. Then we consider the behavior of factor markets in the CGE model. We explain factor mobility assumptions, which govern the readiness of factors to change their employment in response to changing wages and rents across industries. We explore the effects of changes in the supply, or endowment, of factors and contrast it with changes in the "effective" endowment when factor productivity changes. We study the implications of assuming production functions, or industry technologies, that treat factors as complements (low factor substitutability) versus substitutes (high factor substitutability). We describe the CGE model's closures rules that specify full employment versus factor unemployment and demonstrate the importance of this assumption for model results. Finally, we examine the links between factor markets and the industry structure of an economy. We study how a change in factor endowments leads to changes in the industry structure, and we examine how changes in industry structure leads to changes in factor prices and factor input ratios across industries.

Factors of Production Data in a SAM

Each factor of production has its own row and column account in a SAM. For example, in the U.S. 3×3 SAM, there are three factors of production: land, labor, and capital (Table 6.1). The factor row accounts describe the receipt of income earned from employment in agriculture, manufacturing, and services production activities. For example, land receives \$36 billion from employment in agricultural production. Labor receives income from all three production activities: \$47 billion from employment in agriculture, \$1,361 billion from employment in manufacturing, and \$6,797 billion from employment in services. Capital also receives income from all three production activities.

The SAM's factor column accounts report the disposition of factor income. First, there are income taxes based on factor earnings. Land rental income pays \$3 billion in income taxes and labor pays \$1,742 billion in income taxes. The SAM, and the CGE model that we use for most of our examples in this book, assume that the after-tax income of land and labor are paid to the regional household, a macroeconomic account. Capital pays \$294 billion in income taxes. In addition, the capital account column reports depreciation of \$1,260 billion, the replacement cost of worn-out capital that is recorded in the investment-savings account. Capital's remaining income is paid to the regional household account.

CGE models generally have at least two factors of production. Often, researchers disaggregate factors into many more types. For example, they may disaggregate labor into skilled and unskilled workers or urban and rural

Table 6.1. *Factors of Production Data in the SAM ($U.S. billions)*

	Production Activities			Factors		
	Agriculture	Manufacturing	Services	Land	Labor	Capital
Land	36	0	0			
Labor	47	1,361	6,797			
Capital	53	649	2,846			
Income tax	0	0		3	1,742	294
Regional household	0	0		33	6,643	1,994
Savings-investment	0	0	0	0	0	1,260
Total	na	na	na	36	8,205	3,548

Source: GTAP v.8.1 U.S. 3×3 database.

workers. Modelers also may disaggregate the capital account to separate capital equipment and structures from natural capital resources such as coal and oil. Sometimes, CGE modelers disaggregate land into types, such as cropland versus grazing land, or irrigated and nonirrigated land. You can visualize factor market disaggregation in a SAM by imagining that instead of a single labor row and labor column account, there are, for example, two labor rows and two labor columns – one each for skilled and unskilled labor. By disaggregating factors, the researcher who is interested in factor markets can pursue a richer analysis of some types of economic shocks. For example, a labor economist may be interested in differentiating the effects of immigration on skilled versus unskilled wages.

Factor Mobility

Factor mobility describes the ease with which labor, capital, and other factors can move to employment in different production activities *within a country* as wages and rents change across industries. Some multi-country CGE models also allow factor mobility *across* countries, which changes nations' factor supplies. A CGE model of this type supported a recent World Bank analysis of global labor immigration, summarized in Text Box 6.1. In this chapter, we assume a nation's factors are in fixed supply, except when we explicitly consider, as in the next section, the ramifications of a change in factor endowments.

In a CGE model, factors are called *fully mobile* if they are assumed to move among jobs until wage and rent differentials across industries disappear. For example, if workers perceive that one industry offers a higher wage than another does, some number of them will exit the low-wage industry, causing its wage to rise, and enter the high-wage industry, causing its wage to fall. Their movement will continue until wages in the two industries are equal. Full factor mobility is probably a realistic view of labor and capital markets in the medium run or long run, because transition costs, such as retraining and job search costs, become less important when they are amortized over a longer time horizon. Younger workers, for example, may decide it is worth the time and money to invest in training for higher-paying jobs in industries that seem to offer a bright future over the remaining span of their careers.

Some CGE models allow factors to be *partially mobile*. This assumption implies that transition costs are large enough to discourage some workers or equipment from changing employment unless pay differences are sufficient to compensate them for the cost of moving to other employment. Wages and rents can therefore diverge across production activities, and, given identical shocks, factor movements are usually smaller with partially mobile factors than in a CGE model that assumes full factor mobility.

Text Box 6.1. The Economic Impacts of Global Labor Migration

Global Economic Prospects 2006, World Bank, Washington, DC.

What is the research question? The United Nations estimates that international migrants account for about 3% of the world's population. International labor migration can generate substantial welfare gains for migrants, their countries of origin, and the countries to which they migrate, but it may also lead to social and political stresses. What is the estimated size of the economic welfare effect of global labor migration?

What is the CGE model innovation? The authors modify the World Bank's recursive dynamic CGE model, Linkage (van der Mensbrugghe, 2005), to work with their comprehensive global database on labor migration, which differentiates between migrant and native workers and tracks remittance income sent by migrants to their countries of origin. They also adapt their welfare measure to account for the effects of cross-country differences in the cost of living on the spending power of migrant wages and remittances.

What is the model experiment? Migration flows from developing to high-income countries are assumed to increase at a rate sufficient to increase the labor force of high-income countries by 3% over the 2001–2025 period. The assumed increase, roughly one-eighth of a percentage point per year, is close to that observed over the 1970–2000 period.

What are the key findings? Migration yields large increases in welfare for both high- and low-income countries. Migrants, natives, and households in countries of origin all experience gains in income, although income falls for migrants already living in host countries. There is a small decline in average wages in destination countries, but migration's effect on the long-run growth in wages is almost imperceptible. Both the costs and the benefits of migration depend, in part, on the investment climate.

CGE models that allow partial factor mobility use a factor supply function for each partially mobile factor. This concave function is identical to the export transformation function described in Chapter 5, so we do not replicate it here. Using labor as an example, the function describes how a labor force of a given size can be transformed into different types of workers, such as agricultural or manufacturing workers. A *factor mobility elasticity*, σ^F, defines the percentage change in the share of the labor force employed in sector X given a percentage change in the ratio of the economy-wide average wage to its industry wage, holding the factor supply constant. For example, if the wage in sector X rises relative to the average wage, then the share of the workforce employed in sector X will rise. The factor mobility parameter value ranges between a negative number close to zero, which is an almost immobile factor, to –1, which is a fully mobile factor. The higher is this elasticity (in absolute value), the larger are the employment shifts in response to changes in wages

Table 6.2. *Capital Rents by Sector with a 5% Subsidy on U.S. Private Household Consumption of Domestic Manufactures, under Alternative Capital Mobility Assumptions*

	Agriculture	Manufacturing	Services
Fully mobile capital	1.1	1.1	1.1
Partially mobile capital	2.8	4.2	0.1
Sector-specific capital	4.3	4.9	–0.1

Note: Fully mobile capital has a factor mobility elasticity (etrae) of –1, partially mobile capital has an elasticity of –.2 and sector-specific capital has an elasticity of –.0001. The percent change in capital rents is variable *pfe*.
Source: GTAP model, GTAP v.8.1 US 3×3 database.

and rents across industries. CGE models that describe factor mobility in this way may assume a Constant Elasticity of Transformation (CET) factor supply function, so that parameter σ^F is the same for all ratios of factor employment and at all levels of aggregate factor supply.[1]

In the short run, some factors may be immobile, also called *sector-specific*. That is, factors do not move from the production activity in which they originally are employed, regardless of the size of changes in relative wages or rents across industries. This assumption is often made in the case of capital, because existing equipment and machinery are typically hard to transform for use in different industries. Similar to the case of partially mobile factors, the wage or rent of the sector-specific factor can differ across industries in the model – perhaps significantly so, because no amount of wage or rent premium can be enough to attract factors that cannot move, or low enough to motivate them to quit their current employment.

A practical implication of the factor mobility assumption is that it influences the slope of industry supply curves. All else being equal, the more mobile are factors, the more elastic is the supply curve and the larger is the supply response to any type of economic shock. One way to think about it is that a producer who can easily attract more factors with a small wage or rent increase is better able to increase output while holding down production costs, so this producer's supply curve is more elastic.

We explore the effects of alternative factor market assumptions in a CGE model by using the GTAP model and the U.S. 3×3 database to run an experiment that introduces a 5% subsidy to private households in the United States on their purchases of domestically produced manufactured goods. The subsidy stimulates demand for manufactures, so producers try to increase their output by hiring more labor and capital. The results reported in Table 6.2

[1] See the section on export supply in Chapter 5 for a more detailed discussion of CET functions.

describe the subsidy's effects on each industry's capital rents in models with three different capital mobility assumptions: fully mobile, partially mobile, and sector-specific. When capital is fully mobile, it moves across industries until capital rents equalize, so the capital rents increase by the same rate (1.1%) in every industry. In this case, manufacturing output increases 3.7%. When capital is only partially mobile, intersectoral differences in rental rate emerge. Because manufacturers must offer relatively higher rents to attract capital, their rents are now higher than in other sectors and their output expands by slightly less, 3.3%. The capital rent in U.S. manufacturing rises most when capital is assumed to be sector-specific, and manufacturing output increases least in this model, by 3.2%. In this case, the increase in manufacturing output can only be achieved by increasing the ratio of workers to the fixed quantity of capital. This drives up capital's marginal product and therefore its rent.

Factor mobility assumptions are a useful way to categorize CGE model results as describing *short-run*, *medium-run*, or *long-run* adjustments to economic shocks. In the short run, some factors – usually capital – are immobile, and the economy's production response is therefore limited. In the medium run, factors are partially, or even fully, mobile. In this case, the adjustment period is long enough that existing stocks of capital and labor can be retooled or replaced, and workers can shift employment among industries in response to changes in wages and rents. Production therefore becomes more responsive to economic shocks. Analyses of long-run adjustment assume that all factors are fully mobile and, in addition, long-run changes in factor supply and productivity occur. The standard, static CGE models that we are studying can describe short- and medium-run adjustments, depending on their factor mobility assumptions. Dynamic CGE models that are capable of describing factor accumulation and productivity growth are needed to describe long-run adjustments to economic shocks.

Factor Endowment Change

A common assumption in standard CGE models is that a nation's factor endowments are in fixed supply. CGE modelers analyze shocks to factor endowments as model experiments. These shocks can occur for many reasons, such as immigration (increases the labor supply), foreign direct investment (increases the capital supply), or war (decreases both labor and capital supplies). A change in factor endowments can be a significant shock because it changes the productive capacity of an economy. Often more important from a public policy perspective are the resulting distributional effects when a change in a factor endowment leads to increased wages or rents earned by some factors but lower earnings by others.

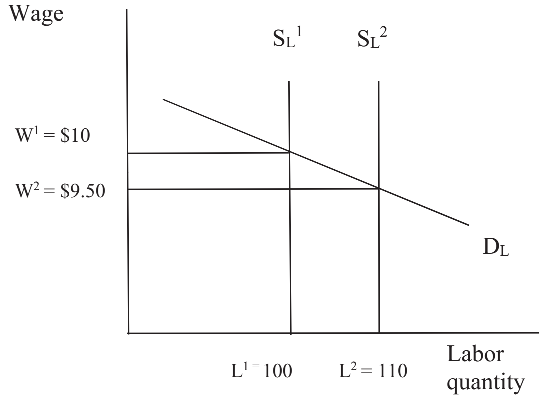


Figure 6.1. Effect of an increase in labor endowment on employment and wages.

An increase in the supply of a factor will cause its wage or rent to fall (unless demand for the factor is perfectly elastic). As an example, Figure 6.1 illustrates the effect of an increase in the supply of labor, from S_L^1 to S_L^2, on employment and wages. The national labor supply curve is a vertical line because we assume, as in a standard CGE model, that there is a fixed supply of workers and all of them are employed. D_L is the labor demand curve. In our example, there are initially 100 workers earning an equilibrium wage, W^1, of $10 per worker. An increase in the labor supply to 110 workers causes the market-clearing wage to fall to $9.50.

We observe the effects on aggregate output and the own-price of a factor endowment change in a CGE model by using the GTAP CGE model and the U.S. 3×3 database to run an experiment that increases the U.S. labor supply by 10%. The result is a 2% decline in the U.S. wage and a 7% increase in U.S. real GDP.

Factors as Complements and Substitutes

A change in the endowment of one factor can also affect the demand for and prices of other factors of production. For example, an increase in the supply of labor – perhaps due to immigration – will affect the wage in the host country, and the demand for and price of capital that is used in combination with labor to produce goods and services. However, we cannot say for sure how immigration will affect capital. Whether the quantity of capital demanded and capital rents will rise or fall depends on whether labor and capital are substitutes or complements in the production process.

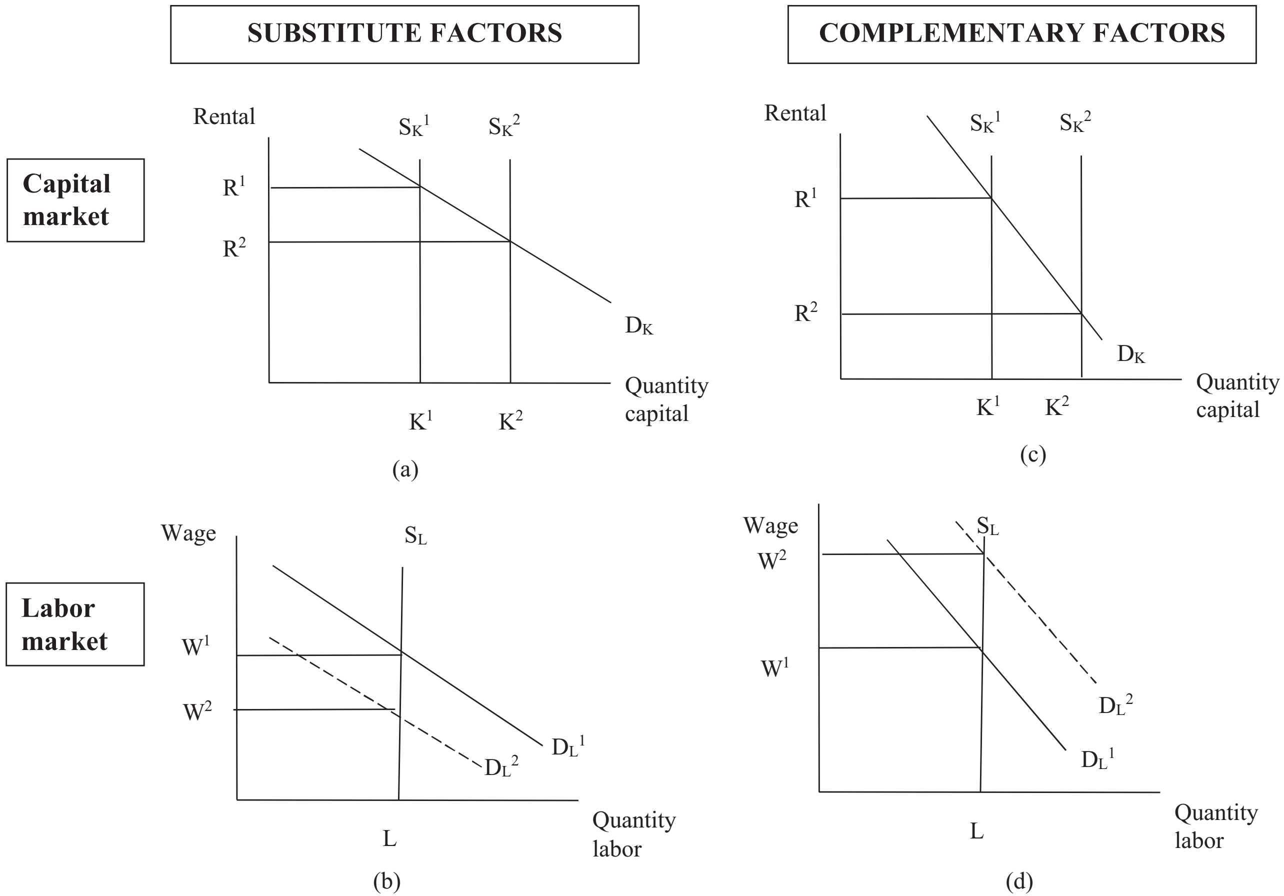
We have already studied factor substitutability and complementarity in our description of producers' demand for value-added in Chapter 5. To reiterate briefly, the firm's technology determines the ability of producers to substitute labor for capital in the production of a given level of output. We depicted the flexibility of technology with a *factor substitution elasticity*, σ^{VA}, which defines the percentage change in the quantity ratio of capital to labor relative to a the percentage change in the ratio of wages to rents, for a given bundle of value added. If the parameter has a large value, the two factors are *substitutes*. As the elasticity approaches zero, the two factors become *complements*.

As an example, consider the case of a country that receives foreign aid in the form of capital equipment and machinery. Will this increase in its capital stock raise or lower its wages – will it help or harm its labor force? Figure 6.2 presents a four-quadrant graph that illustrates the effects of the increased supply of capital goods on the country's capital and labor markets under the alternative assumptions that capital and labor are substitutes or complements. Figures 6.2a and 6.2b describe the markets for capital and labor when the two factors are highly substitutable. Figures 6.2c and 6.2d describe the markets for capital and labor when the two factors are more complementary. Notice that the factor supply curves for both factors are shown as vertical lines, reflecting our CGE model assumptions of fixed factor endowments and full employment. In both capital market figures, an increase in the capital stock shifts the supply curve for capital to the right, from ${S_K}^1$ to ${S_K}^2$. In the two labor market figures, the increase in capital stock shifts the demand curve for labor in opposite directions, from ${D_L}^1$ to ${D_L}^2$.

First, we assume that capital and labor are strong substitutes. Perhaps in this country, industries can easily produce goods using either machinery or workers, so the demand for capital, D_K, is elastic (and drawn with a relatively flat slope) and the initial capital rent is R^1. An increase in the capital stock, from S^1_K to S^2_K, in Figure 6.2a, causes the price of capital to fall so producers substitute toward more cost-saving, capital-intensive production processes. In the new equilibrium, the quantity of capital demanded has increased from K^1 to K^2 and the capital rent has fallen to R^2.

The effect of the increase in capital on the labor market is shown in Figure 6.2b by the direction of the shift in the demand curve for labor. A shift to more capital-intensive processes is shown as a decline in the economy's demand for labor, from D^1_L to D^2_L. As the adoption of more capital-intensive production technologies reduces the demand for the fixed supply of workers, the wage falls from W^1 to W^2.

Contrast this outcome with the case of factors as strong complements. For example, perhaps new capital equipment requires workers to operate it. The demand curve for capital equipment is thus relatively inelastic, with the steep slope shown by D_K in Figure 6.2c. The effect of capital stock growth on the demand for complementary labor is shown in Figure 6.2d as a rightward shift in the labor demand curve, from D^1_L to D^2_L. In this case, the demand for labor increases, causing the wage to rise from W^1 to W^2.



Figures 6.2a–d. Labor and capital as substitutes and complements.

Table 6.3. *Effects of 10% Increase in the U.S. Labor Supply on Wages and Rents in the U.S. 3×3 Model When Factors Are Substitutes or Complements (% change from base)*

% Change	Substitutes	Complements
Wage (pfe_L)	–1.5	–2.0
Rent (pfe_K)	–1.5	5.4

Note: Substitutes case specifies factor substitution elasticities for all production activities of 125. Complements case uses default GTAP v8.1 elasticities.
Source: GTAP model and GTAP v.8.1 U.S. 3×3 database.

We study the role of the factor substitution elasticity in a CGE model by using the GTAP model to carry out an experiment that increases the U.S. labor supply by 10%. We compare the factor price results from two versions of the model. We first define capital and labor as strong substitutes and then as strong complements by changing the factor substitution elasticity parameters for all three production activities in the model.

Model results, reported in Table 6.3, show the key role of the factor substitutability assumption in determining whether a change in the supply of one factor raises or lowers the price of the other factor. When factors are strong substitutes, an increase in the U.S. labor supply lowers U.S. capital rents by 1.5%. If factors are assumed to be strong complements, an increase in the labor supply raises rents by 5.4%. In both cases, an increase in the U.S. labor supply lowers wages.

Factor Productivity Change

Factor productivity describes the level of output per unit of factor input. An increase in factor productivity means that the same quantity of a factor can produce more goods and services. New training, for example, may enable an autoworker to produce twice as many vehicles as previously, whereas bad weather may cause an acre of land to yield only half the usual quantity of wheat. Productivity gains and losses can occur for a single factor (such as the labor productivity losses described in Text Box 6.2) or for a subset of factors, and in one or more industries. Many CGE-based analyses of climate change, for example, describe one of its effects as a reduction in the productivity of land used in the agricultural sector (see Text Box 6.3). A change of equal proportions in the productivity of all factors of production in an industry or in an economy is called a change in *total factor productivity* (TFP).

A change in a factor's productivity changes the *effective factor endowment*. Effective factor endowments take into account both the quantity and the

Text Box 6.2. HIV/AIDS – Disease and Labor Productivity in Mozambique

"HIV/AIDS and Macroeconomic Prospects for Mozambique: An Initial Assessment" (Arndt, 2002).

What is the research question? As in other countries in the southern Africa region, a human development catastrophe is unfolding in Mozambique, where HIV prevalence rates among the adult population in 2000 are around 12%, and life expectancy is projected to decline to about 36 years. Because of the magnitude of the HIV/AIDS pandemic, it has overrun the bounds of a pure health issue and become a top priority development issue. What is the scope of its potential macroeconomic impact?

What is the CGE model innovation? The author develops a recursive dynamic CGE model, based on the IFPRI standard CGE model that updates sectoral productivity, the labor force (by skill category), and the physical capital stock to analyze the effects of HIV/AIDS over time.

What is the model experiment? There are three channels through which the HIV/AIDS pandemic is assumed to affect economic growth: (1) productivity growth effects for labor and other factors; (2) population, labor, and human capital stock accumulation effects; and (3) physical capital accumulation effects. Based on these channels, the author defines four scenarios. An AIDS scenario reduces all factors' productivity and endowments based on available estimates; a "less-effect" scenario reduces most of the HIV/AIDS impacts by about one-half. An education scenario combines the AIDS scenario with a strong effort to maintain school enrollments and the growth of the skilled labor supply. A No-Mega scenario combines the AIDS scenario with the assumption that large-scale, donor-financed investment projects are curtailed.

What are the key findings? The differences in growth rates in the four scenarios cumulate into large differences in GDP over time. GDP is between 16% and 23% smaller than it would be in the absence of the pandemic. The major impacts on GDP are decomposed into the three channels. Although all are important, the decline in factor productivity is the largest source of the potential decline in Mozambique's GDP.

efficiency of a factor. For example, suppose that an initial labor supply of 100 workers can now do the work of 110 workers (a 10% gain in their productivity); then the effective labor endowment is now 110 workers, although the actual number of workers remains at 100.

An increase in productivity tends to lower the wage per effective worker. This point is illustrated in Figure 6.3. Note carefully that its axes and curves refer to the quantity of and wage per effective worker, not actual workers, where EL is the quantity of effective workers. The demand curve for effective labor is D_L, and $S_L{}^1$ describes its supply. In the initial equilibrium, the

Text Box 6.3. Climate Change and Agricultural Land Productivity

"The Distributional Impacts of Developed Countries' Climate Change Policies on Senegal: A Macro-Micro CGE Application" (Boccanfuso, Savard, and Estache, 2013).

What is the research question? Policies to reduce greenhouse gas (GHG) emissions lead to higher prices for energy and for goods that are intensive in the use of energy inputs. Changes in energy prices also can cause changes in an economy's structure of production, leading to changes in relative factor prices. How might Senegal's most vulnerable populations be affected by GHG-mitigation policies undertaken by high-income countries that increase the world price of energy? Might these impacts undermine Senegal's goals for development and poverty reduction?

What is the CGE model innovation? The authors develop a static, single-country CGE model of Senegal that transmits model results for market and factor prices into a rich micro-simulation household module. The model also develops a detailed energy sector that focuses on the use of electricity in the production process and by households.

What is the model experiment? The model explores three scenarios: (1) a 50% increase in global fossil fuel prices because of the adoption of climate change mitigation policies in high-income countries – the domestic electricity price is fixed, with the Senegal government absorbing losses incurred by the domestic utility company; (2) a 50% increase in global fossil fuel prices and rising domestic electricity prices; and (3) scenario 2 plus a 10% decline in productivity of Senegal's agriculture due to climate change.

What are the key findings? Rising energy prices have relatively small effects on poverty and income inequality in Senegal, mainly because energy has a small share in the consumption baskets of poor households. Declining land productivity due to climate change is far more important, negatively impacting the poor by increasing food prices and reducing unskilled wages.

economy employs 100 workers at a wage of \$10. An increase in labor productivity shifts the supply of effective workers to S_L^2. Given the labor demand curve, the new equilibrium has 110 effective workers at a wage per effective worker (the *effective wage*) of \$9.50. It may seem surprising that a factor's productivity gain could lead to a lower wage or rent, but remember that this is the price of an effective factor. Because 110 effective workers equal 100 actual workers, the wage per actual worker has *increased* to \$10.45.[2]

[2] The actual wage is derived by calculating the total wage bill as the product of effective workers times the effective wage (110 ∗ \$9.50 = \$1,045) and dividing it by the number of actual workers (\$1,045/100 = \$10.45).

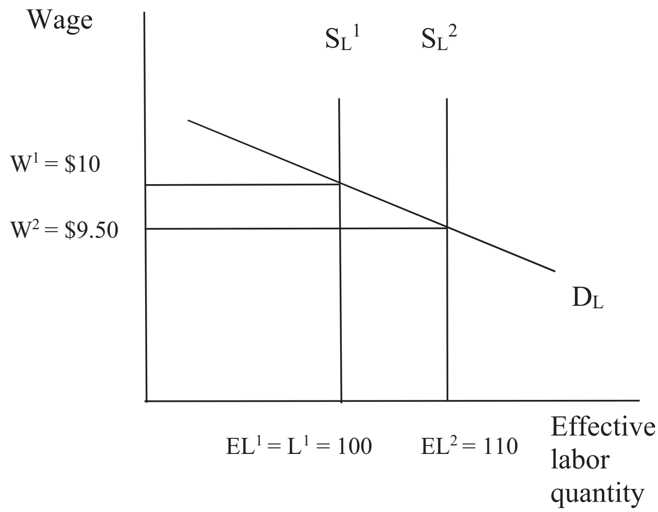


Figure 6.3. Effect of an increase in labor productivity on employment and wages.

Similar to an endowment change, when the effective endowment of one factor changes, it can affect the demand for and prices of other factors. In Chapter 5, we showed how a change in one input price could lead to substitution and output effects on the demand for both factors. In the case of a change in the effective price, we decompose three effects. The first two are the same substitution and output effects that we have already studied. For example, if labor productivity increases, a fall in the effective wage motivates producers to become more labor-intensive and use less capital for any given output level, to the extent that their technology allows it. Automakers, for instance, will want to use more of the newly trained autoworkers and less equipment to produce their current output quantity, because the cost of labor per auto has fallen relative to the cost of capital. This is the substitution effect of productivity changes on the demand for actual workers and for capital. Second, given the competitive markets assumed in standard CGE models, a fall in production costs because of increased productivity is passed on to consumers through lower product prices, which in turn leads to higher demand and production levels. The output effect describes an increase in demand for all factors by the same proportion as the change in output, holding relative factor prices constant. The third, additional effect is the impact of a factor's productivity change on demand for that factor, for a given output level. Automakers, for example, will need fewer workers to produce the same number of cars when labor productivity increases. The net effect of a factor's productivity change on demand for all factors in the economy is the sum of the substitution, output, and productivity effects.

Table 6.4. *Effects of a 10% Increase in Economy-Wide U.S. Labor Productivity on Demand for Labor and Capital (% change from base)*

	Agriculture	Manufactures	Services
Labor demand (*qfe*)	–6.2	–2.1	0.5
Factor substitution effect (*qfe-qo-afe*)	1.7	2.5	2.9
Output effect (*qo*)	2.2	5.4	7.6
Productivity effect (*afe*)	–10.0	–10.0	–10.0
Capital demand (*qfe*)	1.9	–0.3	0.0
Factor substitution effect (*qfe-qo-afe*)	–0.2	–5.8	–7.6
Output effect (*qo*)	2.2	5.4	7.6
Productivity effect (*afe*)	0.0	0.0	0.0

Note: We use the Johansen solution method.
Source: GTAP model, GTAP v.8.1 U.S. 3×3 database.

We illustrate these three effects in a CGE model using the GTAP model with the U.S. 3×3 SAM. Our experiment assumes a 10% increase in the productivity of the total U.S. labor force; for brevity, we report results only for the capital and labor markets. The factor substitution effect leads to a substitution toward labor and away from capital in all three industries as the effective wage falls (Table 6.4). The output effect in each industry is identical for both factors and is the same as the percent growth in industry output. The 10% increase in labor productivity also leads to a reduction of an equal proportion in each industry's demand for workers. Notice that there is no productivity effect on capital demand because its productivity is unchanged in this experiment. On net, the resulting changes in factor demand cause the effective wage (*pfe – afe* in GTAP model notation) to fall by 3.8%, the actual wage to rise by 6.2%, and capital rents to increase by 3.8%.

Factor Unemployment

In some countries, unemployment is a serious problem, and the common CGE model assumption of full employment of all factors may not realistically describe an economy. Unemployment can be depicted in a CGE model by changing the factor market closure. Recall from our discussion in Chapter 2 that model closure is the modeler's decision as to which variables adjust to re-equilibrate markets following an economic shock. With a full employment model closure, a shock to an economy causes wages and rents to adjust until the fixed supply of each factor is again fully employed. In a model with an *unemployment* closure, the wage or rent is assumed to be fixed, and economic shocks can lead to a change in the factor supply – that is, the size of the labor force or the stock of capital will adjust until factor supply and demand are again equal at the initial wage or rental rate.

Table 6.5. *Effects of a 10% Output Subsidy in U.S. Manufacturing under Full Employment and Unemployment Labor Market Closures (% change from base)*

	Labor Unemployment Closure	Full Employment Closure
Manufacturing employment (*qfe*)	35.2	4.1
Manufacturing output (*qo*)	35.6	4.1
Wage (*pfactreal*)	0.0	6.8
Labor supply (*qo*)	35.3	0
Real GDP (*qgdp*)	24.7	0.1

Notes: Unemployment closure defines the U.S. labor supply as endogenous and the real wage (variable *pfactreal*) as exogenous. Initial manufacturing output tax of 1% in base model is changed to a 10% output subsidy.
Source: GTAP model, GTAP v.8.1 U.S. 3×3 database.

In a model that allows unemployment, a decline in the size of the labor force, for example, means that some proportion of workers is now unemployed, so part of the nation's productive capacity is now idled. An increase in the size of the labor force means that previously unemployed workers have now found employment, so the economy's productive capacity expands. In this case, industries are able to hire as many workers or as much equipment as they need following an economic shock, without bidding up wages or capital rents. As you might expect, experiments in a model that allows factor unemployment can result in very large changes in a nation's productive capacity and real GDP. Conversely, a CGE model that assumes full employment describes the reallocation of existing workers across industries; while compositional changes in an economy can yield efficiency gains, there is no change in its productive capacity.

We explore the implications of the factor market closure assumption in a CGE model by comparing the effects of the same experiment in model versions with two different labor market closures. We use the GTAP model and the U.S. 3×3 database to run an experiment that provides a 10% output subsidy in U.S. manufacturing. Model results show that the alternative factor market closures depict very different adjustments by the U.S. economy to the same economic shock (Table 6.5). Notably, when we assume an unemployment closure, there is a large expansion of manufacturing employment and output because the total U.S. labor supply increases by 35.3%. However, if labor is assumed to be fully employed, then manufacturers must compete for workers with other industries in order to expand production. This competition drives up wages and increases manufacturers' cost of production – costs that must be passed on to consumers through higher prices. Manufacturing production therefore does not grow as much in the full-employment scenario compared to the unemployment scenario. In addition, real GDP growth is far larger (24.7%) if previously unemployed workers can be added to the nation's stock of productive resources, compared to only 0.1% growth in real GDP when factors are already fully employed.

Factors and Structural Change

The industry structure of an economy describes the share of each industry in total national output. For example, from Table 3.3, the structure table for the United States, we know that agriculture accounts for 1% of U.S. GDP and services accounts for 81% of GDP. Industry structure is linked to factor markets in two ways. First, all else being equal, an increase (decrease) in the endowment of a factor causes an increase (decrease) in the relative size of industries that are most intensive in the use of that factor. Second, a change in industry structure affects relative factor prices and factor intensities. The relative price of the factor used most intensively in expanding industries rises, and the relative price of the factor used most intensively in declining industries falls, motivating both industries to substitute toward the cheaper factor.

Let's consider the first linkage in more detail. An industry is intensive in the use of the factor that accounts for the largest share of its production costs. Because the increase in the supply of a factor usually lowers its price, the cost savings will be greatest for those firms that use the factor most intensively. For example, a lower wage rate in the U.S. economy would most benefit U.S. services – the most labor-intensive sector in the United States. In the competitive economy that we assume in our CGE model, services producers can therefore lower their sales price by proportionately more than other industries can. This price change will tend to cause demand for and production of services to increase relative to other goods, depending on consumer preferences.

We can observe this linkage in a CGE model by using the GTAP model and the U.S. 3×3 database to carry out an experiment that increases the U.S. labor supply by 2%. This causes the wage in the United States to decline by 0.4%. The greatest cost savings occur in U.S. services, in which labor costs account for 43% of its total production costs. Lower wages cause output to increase in all three sectors, but it increases by proportionately more in services than in other industries (Table 6.6).

Next, we consider the link between *structural change* and factor returns. The structure of a nation's output can change for many reasons. For example, over time, services have become a larger part of the U.S. economy because of rising incomes and consumer preferences, and the role of manufacturing in U.S. GDP has diminished. Trade shocks, such as a foreign embargo on a home country's exports, or a boom in export demand, can also cause structural

Table 6.6. *Effects of 2% Increase in the U.S. Labor Supply on the Structure of U.S. Production*

	Labor Share in Industry Cost	Percent Change in Output (*qo*)
Agriculture	16	0.4
Manufacturing	24	1.1
Services	43	1.5

Source: GTAP model with v.8.1 U.S. 3×3 database.

change in an economy's output. Government programs, such as subsidies and taxes targeted at specific industries, can cause structural change, too. Factor prices change when industries that are expanding and contracting have different factor intensities in their production technologies.

To understand why, consider a simple, two-industry country in which the capital-intensive sector (agriculture) is expanding. The agricultural production process uses one worker and three units of capital per unit of output. The other industry (services) is labor intensive; it uses three workers and only one unit of capital for every unit of output. If agricultural production expands by one unit, it needs to hire three new units of capital and one new worker. However, when three units of capital leave the services industry, nine workers also become available for hire. There is now an excess supply of labor in the economy, which will cause wages to fall relative to rents. As labor becomes cheaper than capital, the agricultural industry has an incentive to become more labor intensive by using more workers per machine (assuming its production technology allows some factor substitution). As the services industry's capital is bid away by agriculture, and with wages falling, service producers have the same incentive to become more labor intensive (assuming their technology allows it). In the new equilibrium, if all workers and capital are re-employed (the full-employment assumption), then wages will have fallen relative to rents, and both industries will have become more labor intensive than they were initially.

We can observe the effects of structural change on factor returns and factor intensities in a CGE model by using the GTAP model and the US3×3 database to run an experiment that introduces a 10% production subsidy to U.S. services, a relatively labor-intensive activity. Results, reported in Table 6.7, demonstrate that structural change that favors the labor-intensive industry causes the wage to rise slightly relative to capital rents, and all three production activities to become more capital intensive. Notice that the land rent declines substantially. This is because the factor substitution elasticity in agriculture is assumed to be very low and agricultural land is in fixed supply in that sector. As a result, the outflow of agricultural labor and capital

Table 6.7. *Effects of a 10% Production Subsidy to U.S. Services on Factor Prices and Factor Intensities (% change from base)*

Land rent (pfe_T)	–25.82
Wage (pfe_L)	9.76
Capital rent (pfe_K)	9.64
Capital/labor input ratio ($qfe_K - qfe_L$)	
Agriculture	0.05
Manufacturing	0.23
Services	0.34

Note: Initial output tax of 2.8% in U.S. services is changed to a 10% production subsidy.
Source: GTAP model, GTAP v.8.1 U.S. 3×3 database.

into the expanding services industry reduces the complementary demand for farm land, and land productivity and the land rental price fall.

Summary

This chapter examined several aspects of factor markets in a CGE model. We first described the factor market data in the SAM, which reports the sources of factor income and factor expenditure on taxes, depreciation, and the regional household account. In the CGE model, factor mobility assumptions govern the readiness of factors to change their employment in response to changing wages and rents across sectors. An economy's supply response is larger when factors are more mobile. Factor endowments are usually assumed to be in fixed supply in standard CGE models, and modelers may change factor endowments as an experiment. We learned that an increase (decrease) in the supply of a factor usually causes its price to fall (rise), but that the effect on demand for and prices of other factors depends on whether the factors are substitutes or complements in the production process. Full employment of all factors is a common assumption in CGE models, but this may not be a realistic depiction of labor markets in many countries. We described the alternative model closures of full employment and unemployment and show how they depict different adjustments by an economy to economic shocks. Finally, we examined the links between economic structure and factor markets. When a change in factor endowments causes relative factor prices to change, it changes the costs of production for industries and leads to an expansion (contraction) in the output of industries whose factor costs have fallen (increased) most relative to other industries. A change in the industry structure of an economy, perhaps because of changing demand or government policies, can lead to changes in the demands for and prices of inputs when the factor intensities of industries differ.

Key Terms

Complementary factors
Effective factor endowment
Effective factor price
Elasticity, factor mobility
Elasticity, factor substitution
Factor endowment
Factor mobility
Factor price
Factor productivity
Full employment
Fully mobile factors
Long run
Medium run
Mobile factors
Partially mobile factors
Sector-specific (immobile) factors
Short run
Structural change
Substitute factors
Total factor productivity
Unemployment

PRACTICE AND REVIEW

1. Provide real-life examples of an industry with a fully mobile factor and an industry with an immobile factor. In a graph, describe and compare their supply curves and the effects of an increase in demand for their products on their output price and quantity.
2. Assume that you are an industry analyst for manufacturers who build the capital equipment used in the manufacture of computer chips. You have been asked to develop and represent an industry viewpoint on a government-funded training program for engineers who can design and produce the chips using your equipment. Explain whether the engineers and your equipment are substitutes or complements in the production of computer chips. Prepare a graph that describes the effects of the training program on the output and price of your computer chip equipment and write a short paragraph explaining your industry's position.
3. Referring to the U.S. 3×3 structure table (Table 3.3), which industry is the most labor intensive? What are the shares of each production activity in the employment of labor? Based on this information, how do you think a production subsidy to services in the United States will affect capital rents and wages, and the labor/capital ratios in the three production activities?

7

Trade in a CGE Model

In this chapter, we present the building blocks for trade policy analysis using a computable general equilibrium (CGE) model. We begin by reviewing the trade data in the Social Accounting Matrix (SAM). Next, we introduce two concepts, the real exchange rate and terms of trade, and explain how they are represented in standard CGE models. We then focus on trade theory as we simulate and interpret the results of two types of shocks: a change in factor endowments that change comparative advantage, and a change in world prices that changes industry structure, trade, and factor returns. We study an example of "Dutch Disease," a problem that illustrates the links between a change in world prices, the real exchange rate, and industry structure. We conclude with an explanation of the role of trade margin costs in international trade.

Since David Ricardo first developed the theory of comparative advantage, showing that nations gain from specializing in the goods that they produce at relatively lower cost, most students of economics have learned that all countries can gain from trade. Yet, many countries are reluctant to move too far or too fast toward free trade. Their reasoning is not inconsistent with Ricardo's theory. Trade and specialization lead to changes in a country's industry's structure and, in turn, to changes in the wages and rents of factors used in production. Therefore, although trade confers broad benefits on a country, it can also create winners and losers. Protecting, compensating, or managing the social and economic transition of those who lose has led many countries to qualify or delay their commitment to global free trade.

Since the early 1990s, CGE models have been widely used to analyze trade policy issues including unilateral trade liberalization, multilateral tariff reforms through the World Trade Organization (WTO), and preferential trade agreements such as the North American Free Trade Agreement (NAFTA) and the European Union's expansion. The contributions made by CGE models rest on their ability to identify which industries will grow or could contract with freer trade, to describe whether labor or capital will gain or could lose from trade reforms, and, perhaps most important, to measure welfare effects, which summarize the overall effects of changing trade policies on an economy's well-being.

In this chapter, we present the building blocks for trade policy analysis using a CGE model. Our objective is to show, through discussion and example, how to use trade theory to understand and interpret the economic behavior observed in a CGE model. We begin by reviewing the trade data in the SAM, which separately reports exports, imports, tariffs and export taxes, and trade margins. Next, we define two concepts, the real exchange rate and terms of trade, and demonstrate how they behave in standard CGE models. We build on these two concepts as we study two types of shocks: a change in factor endowments that changes a country's production and terms of trade, and a change in world prices that affects production and factor returns. We also study the trade and transportation costs incurred in shipping goods from the exporter to the importer, and learn how changes in these costs can influence world trade flows.

Trade Data in a SAM

Import data are reported in the SAM as an expenditure by the import variety of each commodity column account. The import data separately report spending on import tariffs, trade margin costs, and the cost of the imports (valued in foreign *fob* export prices). For example, the United States spends a total of \$34 billion on imported agricultural goods (Table 7.1). Of this amount, \$1 billion is spent on import tariffs, \$5 billion is spent on the trade margins (insurance and freight charges) that brought the goods from foreign ports to the United States, and \$28 billion is the amount paid to agricultural exporters in the rest of the world. The United States spends a total of \$2,250 billion on imports, of which \$2,140 billion is paid to exporters and the remainder is spent on U.S. import tariffs (\$24 billion) and trade margin costs (\$86 billion) for the shipment of its imports.

Table 7.1. *Import Data in the SAM (\$U.S. billions)*

	Commodity–Import Variety			
	Agriculture	Manufacturing	Services	Total
Tax–imports	1	23	0	24
Trade margin–imports	5	81	0	86
Rest-of-world	28	1,797	315	2,140
Total	34	1,901	315	2,250

Source: GTAP v.8.1 U.S. 3×3 database.

Table 7.2. *Export and Trade Balance Data in the SAM ($U.S. billions)*

Commodity–Domestic Variety	Mfg. Commodity Domestic Variety	Trade Margin–Export	Rest-of-World
Agriculture	0	0	52
Manufacturing	0	0	970
Services	0	28	345
Savings–investment (trade balance)	0	58	773
Export taxes	3	0	0
Total	–	86	2,140

Source: GTAP v.8.1 U.S. 3×3 database.

The SAM decomposes export data into spending on export taxes, the value of exported trade margin services, and the value of all other types of exported goods and services. Exports are recorded in the domestic commodities' row accounts, shown in Table 7.2. For example, the agricultural commodity exports $52 billion worth of agricultural products to the rest-of-world account. The SAM's domestic commodity column accounts pay export taxes. In the United States, only manufacturing pays export taxes, which total $3 billion, so, for brevity, we do not include the columns for domestic agriculture or services. The column account for export trade margins reports the export of U.S.-produced services to the global trade and transport industry ($28 billion). The rest-of-world column account reports foreign purchases of U.S.-produced goods and services. These U.S. exports total $1,367 billion ($52 + $970 + $345 billion), valued in U.S. *fob* world export prices.

The U.S. balance of trade in trade margins is a deficit of $58 billion (the difference between $86 billion spent on trade margin services used to transport its imports and $28 billion of exported margin services). The U.S. trade balance in goods and services, also a deficit, is the value of exports minus the value of imports, both valued in world *fob* prices: $2,140 – $1,367 = –$773 billion. Both deficits are reported as positive payments by the trade margin and rest-of-world accounts to the savings-investment row of the SAM because these are inflows of foreign savings to the United States. The total U.S. trade deficit is the sum of the two trade deficits: $831 billion.

Exchange Rates

CGE models differ in their treatment of the exchange rate. Some have a *nominal exchange rate* variable that describes the rate at which currencies can be exchanged for one another. Usually, it is expressed as units of domestic currency per unit of foreign currency. For example, the exchange rate (EXR) of the Canadian dollar (the domestic currency) relative to the euro (the foreign currency) is defined as the number of dollars that can be exchanged for one euro:

$$\text{EXR}_{\text{CAN,EU}} = \$/\text{euro}.$$

When this type of CGE model includes country SAMs that are denominated in different currencies, the initial value of the exchange rate is the market rate that prevailed in the year corresponding to the SAM database. For example, the Canadian dollar exchange rate would be 1.45 in a CGE model of Canada and the European Union with a 2016 database. More often, all SAMs in a CGE model are denominated in the same currency, such as U.S. dollars, or the CGE model has a single country. In these cases, the researcher defines the initial value of the exchange rate as one.

A rise in a country's exchange rate signals home currency depreciation because more domestic currency is required in exchange for the same quantity of foreign currency. For example, a rise in the Canadian dollar exchange rate from \$1.45/euro to \$1.50/euro means that its dollar has depreciated relative to the euro. Conversely, a fall in the exchange rate signals home currency appreciation.

The nominal exchange rate may seem like a financial variable, but remember that a standard, real CGE model does not account for financial assets or describe financial markets. Instead, the nominal exchange rate is a model variable that determines the *real exchange rate* which is the relative price of traded to non-traded goods.[1] Traded goods are products that are imported or exported. Non-traded goods are products that are produced by, and sold to, the domestic market.

Let's first consider the import side. To simplify, we describe a single-country CGE model with a nominal exchange rate with the rest of the world. For clarity, we assume there are no taxes or trade margin costs and that the country is small in world markets. Recall from our discussion of import demand in Chapter 4 that consumers buy a composite commodity, such as autos, composed of the imported and domestically produced (non-traded) varieties. A change in the exchange rate affects the domestic consumer import price, PM, of the country's imported variety:

$$\text{PM} = \text{EXR} * \text{PWX}$$

where PXW is the fixed world price of the import in foreign currency and EXR is the exchange rate expressed in terms of the importer's currency.

[1] See Robinson (2006) for a more detailed discussion of the role of a nominal exchange rate variable in a standard CGE model in changing the relative prices of traded to non-traded goods in domestic markets. McDougall et al. (2012) describe the real exchange mechanism in the GTAP model.

Because the price of the domestically produced variety in the importing country, PD, does not change, a change in the nominal exchange rate will change the price ratio PD/PM, which is the real exchange rate. Let's assume that EXR rises (i.e., a depreciation); then, the price ratio of PD/PM will fall. Depending on the size of the Armington import substitution elasticity, the quantity ratio of the import to the non-traded variety in the consumption bundle will decline.

As an example, assume that Mexico is a small country in the world market for its apple imports and faces a fixed world price of the import, denominated in U.S. dollars, of $1 per apple. Given an initial EXR of one peso per dollar, its domestic import price for an apple is one peso. Assume, too, that the Mexican peso depreciates to 1.5 pesos per dollar. Mexican consumers now must pay more (1.5 pesos) for each imported apple. As imports become relatively expensive, Mexican demand will shift toward the domestic variety, subject to consumer preferences as described by the import substitution elasticity. Conversely, if the peso appreciates, then the relative cost of imported apples in terms of pesos will fall and consumption will shift toward imports.

Likewise, recall from our discussion of export supply in Chapter 5 that the producer's decision to allocate production between domestic and export sales depends on the relative prices in the two markets. A change in the nominal exchange rate variable, expressed in terms of the currency of exporting country, will change the *fob* export price (PWE) in domestic currency that is received by producers of the exported variety:

$$\mathrm{PWE} = \mathrm{EXR} * \mathrm{PXW}$$

where PXW is the fixed world price of the export. Because the producer price of the domestically produced variety sold in the exporting country, PDS, does not change, a rise in the exchange rate variable (depreciation) will decrease the price ratio PDS/PWE. Depending on the size of the export transformation elasticity, the export share of production will increase.

Let's assume that Mexico is small in the world market for its exports, too, and faces a fixed world export price for oranges, denominated in dollars, of $1 each. Initially, producers receive an export price of one peso per orange. A depreciation of the peso to 1.5 pesos per dollar generates more pesos for any given quantity of exports. Mexican producers will shift their sales toward the export market, subject to technological feasibility. Conversely, exchange rate appreciation would cause a fall in peso earnings from any given quantity of exports, so producers will shift their sales toward the domestic market.

The nominal exchange rate variable may be either flexible or fixed in value, depending on the model's macro closure. In practice, modelers often assume a closure in which a flexible exchange rate variable adjusts to maintain a fixed current account balance. The current account balance is the trade balance (the *fob* values of exports minus *cif* values of imports) plus other

Table 7.3. *Causes and Effects of a Change in the Nominal Exchange Rate Variable on Traded Quantities When the Current Account Balance Is Fixed*

Cause	Change in Nominal Exchange Rate Variable	Effect on Opposite Trade Flow
Imports rise	Depreciation	Exports rise
Imports fall	Appreciation	Exports fall
Exports rise	Appreciation	Imports rise
Exports fall	Depreciation	Imports fall

international monetary flows. One reason that modelers choose this closure is because changes in the current account balance are determined in part by macroeconomic and financial forces that lie outside the scope of real CGE models. It is therefore straightforward and transparent simply to fix the current account balance at the level observed in the initial equilibrium. A second reason is that most countries today have floating exchange rates; however, this is not always the case, and this closure decision offers the modeler the ability to explore alternative exchange rate regimes.

Table 7.3 describes how a flexible nominal exchange rate variable adjusts to equilibrate a fixed current account balance. We assume fixed world prices and observe the quantity adjustments to import demand and export supply. Suppose, for example, that a country's imports increase, perhaps because the country has removed its import tariffs. Its current account balance will worsen as the value of imports grows relative to exports. The exchange rate variable will therefore depreciate, both causing export quantities to rise and dampening the initial increase in import quantities, until the initial current account balance is restored.

The nominal exchange rate is a macroeconomic variable because it affects the relative prices of all traded and non-traded goods by the same proportion. For example, an exchange rate depreciation of 10% would increase the import price of apples, oranges, steel, and all other imported goods by 10% relative to domestically produced apples, oranges, steel, and other goods.

Some CGE models do not have an explicit, nominal exchange rate variable, but they nevertheless include a real exchange rate mechanism. In the GTAP model, for example, the *pfactor* variable describes the percent change in an index of a country's factor prices relative to the world average factor price, which is the model numeraire. In competitive markets, a change in wages or rents paid by a producer will cause changes in the sales prices of his goods. An increase in a country's *pfactor* variable is therefore similar to a real exchange rate appreciation, because an increase in its factor prices will lead to an increase in the price of its domestically produced goods relative to imports, and a shift in its consumption bundle toward imports. The increase in factor prices also will cause the price of its exports to increase relative to the price of domestically produced goods in its trade partner's market. Like a real exchange rate appreciation, this causes foreign consumers to shift their consumption bundle away from the appreciating country's exports. A decrease in a country's factor prices will likewise have similar effects of reducing imports and increasing its exports as a real exchange rate depreciation.

For example, consider two countries (A and B) that both produce apparel. A shock that lowers economy-wide wages in country A causes its price of apparel to fall relative to the price of apparel produced in the higher-wage country B. Indeed, all goods produced in country A using labor become cheaper in the world market than similar goods from country B. This will stimulate A's consumers to shift from imports toward domestic goods in their consumption, and will lead country B's consumers to shift toward imports from domestic goods. Thus, a change in relative factor prices leads to adjustments that are similar to those of a real exchange rate depreciation in A.

Terms of Trade

Terms of trade measure the import purchasing power of a country's exports. Any change in the terms of trade therefore affects an economy's well-being, or welfare, by changing its consumption possibilities. Terms of trade are calculated as the ratio of the price of a country's export good to the price of its import good. Prices are compared in *fob* prices, exclusive of trade margins, otherwise a change in shipping costs would appear to change the relative prices of the two goods. Import tariffs are also excluded.

As an example, consider a two-country, two-good world in which the home country (country A) exports corn to its trade partner (country B), and B exports oil to A. Country A's terms of trade is the ratio of A's *fob* export price of corn to B's *fob* export price of oil, and vice versa. A terms-of-trade improvement for A means that the price for its corn export has increased relative to the price of its oil import. The corn price may have increased or the oil price may have fallen, or both may have changed, as long as the corn price rose relative to the oil price. A's terms-of-trade improvement means that the export earnings from each unit of its corn exports now has more import-purchasing power for oil imports.

Table 7.4 presents two numerical examples to illustrate this concept. Because the price data are reported in percentage change terms, the percentage change in a country's export price minus the percentage change in its import price approximately measures the percentage change in its terms of trade. In scenario 1, country A experiences a terms-of-trade gain because its export price rises relative to B's export price; but A experiences

Table 7.4. *A Two-Country Example of Terms-of-Trade Changes*

	% Change from Base			
	A's *fob* World Export Price of Corn	B's *fob* World Export Price of Oil	A's Terms of Trade	B's Terms of Trade
Scenario 1	25	–10	35	–35
Scenario 2	–2	8	–10	10

a terms-of-trade loss in scenario 2. Notice, too, that A's terms-of-trade gain is exactly equal to country B's terms-of-trade loss, so globally, the terms-of-trade changes sum to zero.

Countries usually export and import many types of goods with many trade partners. A global CGE model that tracks bilateral trade flows and includes the Armington assumption that goods are differentiated by origin tracks the bilateral export prices for all countries and commodities in the model. In this case, a country's terms of trade can be calculated as a price index that is defined for either an industry or for total imports and exports. Either index is calculated as a trade-weighted sum of the home country's bilateral (*fob*) export prices relative to a trade-weighted sum of the *fob* prices of its imports. The trade weights on the export side are the quantity shares of each trade partner in the home country's export market. The weights on the import side are the quantity shares of each source country in the home country's imports.[2] Terms-of-trade changes can vary widely among countries, even though globally, the terms-of-trade changes for all countries sum to zero.

A *"small" country* does not experience terms-of-trade effects because its world market shares are too small for changes in its export and import quantities to affect world prices. Single-country CGE models often, but not necessarily, include the assumption that a country is small in world markets and that its world export and import prices are fixed. However, in multi-country CGE models with Armington import aggregation functions, every country is potentially a *"large" country* to some extent – even countries that we ordinarily think of as small. Therefore, all countries in a multi-country model can experience terms-of-trade changes.

An important, practical implication of the use of Armington functions in multi-country CGE models is that terms-of-trade effects are usually due to larger changes in countries' export prices than in their import prices. This insight was developed by Brown (1987), who studied terms-of-trade effects in the multi-country Michigan Model of international trade. To understand

[2] See Chapter 2 for an example of how to calculate a trade-weighted price index.

why this is so, consider what might happen if a very small country like Israel imposes a tariff on its orange imports, causing its consumers to reduce their import quantity and consume more domestically produced oranges. Israel's bilateral import prices for oranges will likely fall, but not by much, since Israel is only one of many customers in each of its suppliers' markets, and probably only a small one at that. However, even a small country like Israel is large in its export market because the Armington assumption – that products are differentiated by source country – implies that Israel is the monopoly supplier of Israeli oranges. Increased domestic demand reduces the supply of Israeli oranges available for export. When the quantity of Israeli orange exports declines, its world export price will rise, perhaps by a lot if its foreign customers are unwilling to substitute their domestic oranges, or oranges from other suppliers, for the Israeli variety (i.e., they have a low Armington import substitution elasticity)

We explore these concepts in a CGE model by using the ESUBrToy CGE model and the U.S. 3×3 database to run an experiment that increases the U.S. manufacturing import tariff from 1.2% to 15%.[3] We compare the terms-of-trade results for the U.S. manufacturing sector when the U.S. elasticity of substitution between domestic and the aggregate imported variety is assumed to have a relatively low value of 3 versus a high value of 8.

The tariff increases the price paid by U.S. consumers for manufactured imports from the rest-of-world and causes the U.S. import demand quantity to fall (Table 7.5). The higher the import substitution elasticity, the greater the fall in the U.S. import quantity. The United States is a large enough customer that a decline in its import demand causes the rest-of-world's bilateral export price to fall, the more so as the import becomes more substitutable with the domestically produced variety.

On the export side, the shift of U.S. demand toward the domestic variety causes a fall in the quantity of U.S. manufacturing available for export. The higher the U.S. import substitution elasticity, the larger the decline in the U.S. export supply. The decreased availability of U.S. exports drives up the price of U.S. manufacturing exports, the more so as import becomes more substitutable with the domestic U.S. product. On net, the United States

[3] In the standard GTAP model, Armington import demand and factor substitution elasticities vary by commodity but are identical across all countries. The ESUBrToy model is an adapted version of the standard GTAP model developed by Jayson Beckman of the U.S. Department of Agriculture. ESUBrToy allows us to define these parameters by country and commodity. Note that the GTAP model includes a third stage in the consumer decision that, for a given quantity of imports, describes the sourcing of imports from among suppliers. In this experiment, we define Armingon import-import substitution elasticities across import suppliers to be twice the level as that between the domestic variety and the composite import. ESUBrToy can be downloaded from www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=4841

Table 7.5. *Terms of Trade Effects on U.S. Manufacturing from a 15% U.S. Tariff on Manufactured Imports (% change from base values)*

U.S. Armington Import-Domestic Substitution Elasticity	Mfg. Import Quantity (*qiw*)	Mfg. Export Quantity (*qxw*)	Bilateral ROW Mfg. Export Price to United States ($pfob_{ROW}$)	Bilateral U.S. Mfg. Export Price to ROW ($pfob_{US}$)	U.S. Terms of. Trade in Mfg. ($pfob_{US}$)–($pfob_{ROW}$)
3	–17.2	–22.7	–0.6	4.1	4.7
10	–37.1	–25.9	–0.9	4.4	5.3

Note: U.S. tariff on manufactured imports is increased from 1.2% to 15%. U.S. import substitution elasticity among import suppliers is twice the level of the domestic/import Armington elasticity.
Source: ESUBrToy model, GTAP v.8.1 U.S. 3×3 database.

has a terms-of-trade gain that becomes larger as its import substitution elasticity becomes larger. Notice that most of the U.S. terms-of-trade gain is attributable to an increase in the U.S. export price.

Terms-of-trade effects can be an important outcome of any type of shock to an open economy. Many CGE analyses of trade liberalization find that the terms-of-trade effects are quite large and can even dominate efficiency gains in determining the welfare effects of trade policy reform. However, even when the modeler makes the small-country assumption and fixes the terms of trade, this variable remains a relevant subject of CGE analysis because exogenous changes in the world import or export price can be introduced as an experiment. As an example, the modeler could explore the effects of an increase in the world price of a natural resource export on a small, resource-exporting country, as we do later in this chapter in our discussion of Dutch Disease.

Trade Theory in CGE Models

Economists Eli Heckscher and Bertil Ohlin developed a simple, two-good, two-factor, two-country model to explain the relationship between countries' relative factor endowments and the composition of their trade. In their stylized model, the two countries differ only in their relative factor endowments – one has a larger endowment of labor relative to capital, and the other has a larger endowment of capital relative to labor. The *Heckscher-Ohlin theorem* posits that both countries will export goods that are intensive in the factors of production that are in relatively abundant supply, and import goods that are intensive in the factors of production that are in relatively scarce supply.

This powerful insight into why countries trade has yielded additional theorems about trade. Two theorems that derive from the Heckscher-Ohlin model describe the effects of changes in factor endowments on industry structure and the terms of trade (the *Rybczynski theorem*), and the effects of changes in world prices on factor returns and income distribution (the *Stolper-Samuelson theorem*). Both theorems focus attention on the effects of changing market conditions on economic structure and factor income, and so they are of special interest to CGE modelers, because these are the outcomes that we largely focus on in our studies.

However, the two theorems rest on very specific assumptions that are not usually met in the more realistic, applied CGE models that we are studying. For example, in our U.S. 3×3 model, the two regions both export and import the same type of good, and their production technologies differ. In many applied CGE models, there are more factors, more industries, and (in multi-country models) more countries than in the stylized theoretical models that yield these theorems. Nevertheless, grounding our interpretation of CGE model results in these theorems remains useful. In the following sections, we show how the theorems help us identify which model results are most relevant to consider, and how they provide us with insights that help us understand and explain our results. Results tend to be consistent with, although they do not necessarily follow directly from, the stylized models of international trade.

Factor Endowment Changes, Trade, and Terms of Trade

A country's factor endowments can change for many reasons. Over the long term, economies grow because of the gradual accumulation of factor supplies, as savings augment the capital stock and population growth increases the labor supply. Economic shocks also affect factor supplies such as labor immigration, capital inflows, and war and disease. And, as we learned in Chapter 6, a change in productivity changes the effective endowment of a factor. Education and training, for example, increase the effective number of workers, even if the actual number of workers remains the same.

A change in factor endowments can change a country's comparative advantage and lead to changes in the types of goods that it produces and trades. In turn, changes in a country's export supply and import demand can lead to changes in its terms of trade. These ideas were developed formally by the economist Tadeusz Rybczynski (1955). He posited that a change in the endowment of one factor has two effects. First, an increase in the quantity of one factor leads to an absolute increase in the production of the good that uses that factor intensively, and an absolute decrease in production of the good that does not use it intensively, holding world prices constant

Text Box 7.1. Rybczynski Effects in a Global CGE Model of East Asia

"Historical Analysis of Growth and Trade Patterns in the Pacific Rim: An Evaluation of the GTAP Framework" (Gehlhar, 1997).

What is the research question? A CGE model's validity is often tested by scrutinizing assumptions about behavioral equations and their elasticity parameters. This analysis proposes a more rigorous test by asking whether the GTAP model is capable of explaining and reproducing historical trade flows.

What is the CGE model innovation? The author performs an exercise in "backcasting" (as opposed to "forecasting") by seeing whether the GTAP model can replicate historical, bilateral trade flows. Because the GTAP model is based on standard, neoclassical theory, the author chooses a backcasting exercise that the theory is capable of explaining – the link between factor endowments and the commodity composition of trade. In general, East Asian countries are observed to have had faster growth in their human and physical capital stocks over 1982–1992 than developed countries, and the composition of their exports has consequently shifted from labor intensive to skill- and capital-intensive products. The author uses the CGE model to reverse East Asia's factor endowment growth and observe model results for Rybczynski-type effects on industry structure and trade.

What is the experiment? For each country/region, four types of endowments are reduced from their 1992 levels to 1982 levels: population, labor force, human capital, and physical capital. The same experiment is carried out with (1) the default import substitution elasticities, (2) a 20% increase in all import elasticities, (3) a database that disaggregates the labor force into skilled and unskilled workers, and (4) a combination of the human capital split and higher import substitution elasticity parameters.

What are the key findings? There is a strong correlation between countries' actual 1982 shares in world trade by commodities and the trade shares simulated by the model. The correlation is strongest when trade elasticities are relatively large and labor is divided into skilled and unskilled workers. The comparison of correlations across the four scenarios demonstrates that elasticities and labor market disaggregation by skill level are critical assumptions in terms of the model's predictive ability.

(Table 7.6). This observation is known as the Rybczynski theorem. Second, if the country engages in trade and if the quantity of the endowment used intensively in its export good increases, then its export supply and import demand will increase and its terms of trade will deteriorate. On the other hand, if the endowment used intensively in the importable good increases, then the country's imports and exports will decline and its terms of trade will improve.

Table 7.6. *Endowment Growth and Rybczynski Effects*

Endowment Growth	Exportable Output	Importable Output	Terms of Trade
Factor used intensively in exportable	+	−	−
Factor used intensively in importable	−	+	+

Figure 7.1 illustrates the producer's efficiency-maximizing behavior that drives the Rybczynski theorem. First, assume that there are two sectors in the economy: one that produces exportable goods and one that produces importable goods. We also assume that the exportable sector is labor intensive and the importable sector is capital intensive. The figure includes a product transformation curve, QO^1, drawn concave to the origin. It represents all possible combinations of outputs of the exportable, QE, and importable, QM, goods that can be produced with a given factor endowment. Recall from Chapter 5 that the slope of any point on a transformation curve describes the marginal rate of transformation (MRT), which is equal to the ratios of the marginal costs of the importable to the exportable: MC_M/MC_E. As the economy moves down the transformation curve and relatively more of the importable good is produced, the prices of the importable's inputs are bid up, and the ratio MC_M/MC_E increases. The parallel lines in the figure define the relative world prices of the country's export (PWX) and its import (PWM). For now, we assume that world prices are fixed, and the country is small in world markets, so both price lines have the same slope $-PWM/PWE$. In the initial equilibrium, output is at quantity ratio QM^1/QE^1. At this tangency, the

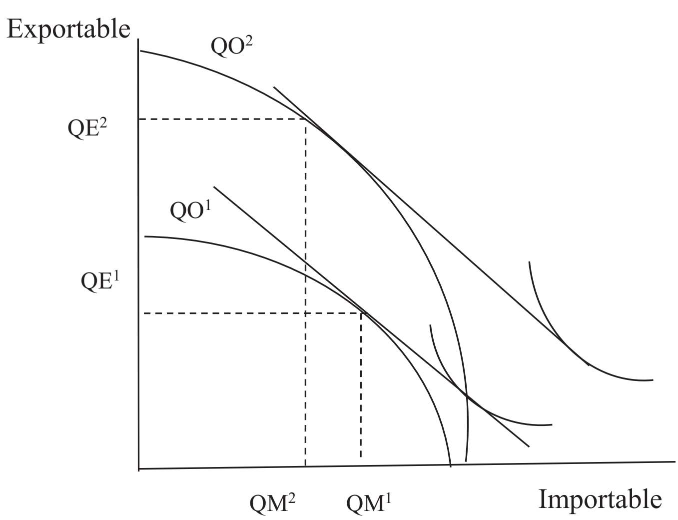


Figure 7.1. Exportable-expanding factor growth.

ratios $MC_M/MC_E = PWM/PWE$. Rearranging, $MC_M/PWM = MC_E/PWE$. This means that the producer optimizes when the marginal cost per dollar earned from the sale of both goods are equal.

In the figure, the convex curves are consumer indifference curves that describe all possible combinations of the exportable and importable good that yield equal utility to domestic consumers. Notice that the country's utility-maximizing consumption basket is different from its optimal production mix. In this country, international trade gives consumers the opportunity to consume a larger ratio of importable to exportable goods than it produces.

An increase in the country's labor endowment shifts its product transformation curve outward to QO^2. Now, more of both goods can be produced. The increase in the labor supply drives down wages, which is most cost saving for the exportable sector because it is relatively labor intensive. That is why the curve shifts out further on the exportable axis than on the importable axis. The fall in the wage causes MC_E to fall relative to MC_M at the initial product ratio of QM^1 and QE^1. The economy adjusts by shifting toward production of the labor-intensive exportable, which drives wages back up until the marginal cost per dollar earned from exportables is again equal to that from importable production. At given world prices, the optimal production mix is now QE^2 and QM^2.

The increase in supply of exportables leads to an increase in export supply, and the decline in importable production leads to higher import demand. If we now assume that the country is large enough in world markets to affect world prices, then the world price of its exportable will fall, and the world price of its importable will rise. That is, the country's terms of trade will decline.

The effect of an increase in the capital stock, used intensively in the importable good, is analyzed in a similar fashion. In this case, production of the importable increases and import demand falls. Production of the exportable and export supply both fall. The changes in the country's trade will lead to an improvement in its terms of trade.

This is the theoretical context for understanding the trade, and terms-of-trade, effects of CGE model experiments that increase the endowment of one factor. However, before we can explore Rybczynski effects in our CGE model, we first need to examine the U.S. 3×3 data to compare factor intensities across sectors and to identify which sectors are exportable or importable. Based on data from the U.S. structure table (Table 3.3) on labor and capital shares in industry costs, we know that land accounts for 11% of the cost of producing agricultural products, but is not used in the production of manufacturing or services. Commodities are more exportable as the export share in production increases, and more importable as the import share in

Table 7.7. *Effects of a 10% Increase in the U.S. Land Supply*

		World Price of U.S.					
	Labor Share in Industry Costs	Output (qo)	Exports (qxw)	Imports (qiw)	Export ($pfob_{US}$)	Imports ($pfob_{ROW}$)	Terms of Trade ($pfob_{US} - pfob_{ROW}$)
Percent							
Agriculture	11.00	0.37	1.40	–0.69	–0.37	–0.07	–0.30
Manufacturing	0.00	0.02	–0.01	0.03	0.00	0.00	0.00

Note: Elasticity of factor substitution is four in all sectors.
Source: GTAP model, GTAP v.8.1 U.S. 3×3 database.

consumption increases. According to data from the U.S. structure table, the agriculture sector is relatively exportable, with a higher share of exports in production than of imports in consumption. U.S. manufacturing is a relatively importable sector, with a higher share of imports in consumption than of exports in production. Services are close to being a non-traded good, a possibility not considered in Rybczynski's stylized two-sector model and another example of how our applied model diverges from the strict assumptions of theory.

With this grounding in theory and in our model data, we can use the GTAP model with the U.S. 3×3 database to analyze a change in a factor endowment on the two relatively tradable sectors: agriculture and manufacturing. Our experiment is a 10% increase in the U.S. land supply, which is an increase in the endowment used in the more exportable sector. The shock causes U.S. land rents to fall by 3%. The U.S. experiences a small real appreciation of .01% because its factor price index increases relative to that in the rest of the world.

Other results, reported in Table 7.7, are broadly consistent with the Rybczynski effects. Production increases by more in the land-using agricultural sector than in manufactures, although output in both sectors increases because growth in the U.S. land supply increases the productive capacity of its economy. The increase in U.S. agricultural supply results in an expansion of U.S. agricultural exports and a decline in agricultural imports. The supply of U.S. manufacturing exports falls and imports increase, although these trade changes are too small to impact world prices. Terms-of-trade results, too, are consistent with Rybczynski effects. The U.S. *fob* export price declines in the exportable sector by more than in its import price (the rest-of-world *fob* export price), resulting in a terms-of-trade loss in agriculture. World price effects in manufacturing are too small to report. The Rybczynski prediction that the overall U.S. terms of trade will decline is thus supported by our model.

Text Box 7.2. Stolper-Samuelson vs. Migration Effects in NAFTA

"Wage Changes in a U.S.-Mexico Free Trade Area: Migration versus Stolper-Samuelson Effects" (Burfisher, Robinson, and Thierfelder, 1994).

What is the research question? Much of the debate over NAFTA reflected concerns about potential wage changes as described by the Stolper-Samuelson theorem (SST). The theorem suggests that NAFTA will lower unskilled wages in the United States and raise those in Mexico as free trade causes the exports and prices of Mexico's unskilled labor-intensive exports to increase and the production and price of these goods in the United States to fall. However, wages in both countries are also influenced by the impact of NAFTA in increasing labor migration flows within Mexico and between Mexico and the United States. Could an applied CGE model of a free-trade agreement between the United States and Mexico predict the wage effects from both SST effects and migration?

What is the CGE model innovation? The authors develop a CGE model of the United States and Mexico that allows labor migration between the two countries in response to changes in relative wages. The model also includes tariffs and domestic taxes and subsidies that are not directly affected by the NAFTA accord and which create a second-best environment that violates many of the assumptions of the SST.

What is the experiment? The model experiments describe tariff elimination between the United States and Mexico in (1) a realistic model with tax distortions and (2) a distortion-free model that replicates some (but not all) of the assumptions of the SST. A trade liberalization experiment is run in the model without migration to explore SST effects, and in the model with labor migration to describe combined SST and factor endowment effects.

What are the key findings? The SST effects are found to be empirically very small, and labor migration has the dominant influence on wages in the free-trade area, in some cases reversing the wage changes that would be expected based on the SST alone.

World Price Changes and Factor Income Distribution

What happens to a country's wages and capital rents when world prices change? The Stolper-Samuelson theorem posits that in a two-good economy, a change in the relative prices of goods will lead to a change in relative factor prices and the distribution of national income. The price of the factor used intensively in the production of the good whose relative price has risen will increase. The price of the factor used intensively in the production of the good whose relative price has decreased will fall.

The reasoning is as follows. An increase in the world price of one good will cause an economy's production to shift toward increased production of that good and away from production of the other good. If each industry employs a different mix of factors, then the composition of the economy-wide demand for factors will shift, leading to a change in relative factor prices. As an example, let's assume that the world price of agriculture (a relatively capital-intensive good) increases relative to the world price of manufactures (a relatively labor-intensive good). To expand agricultural output, farmers must hire capital and labor from the manufacturing industry. As the manufacturing industry contracts, it releases both labor and capital, but the proportion of labor is too high and the proportion of capital is too low relative to the demands of agriculture. Given its scarcity, the increased demand for capital will push capital rents up while the surplus of labor will push wages down.

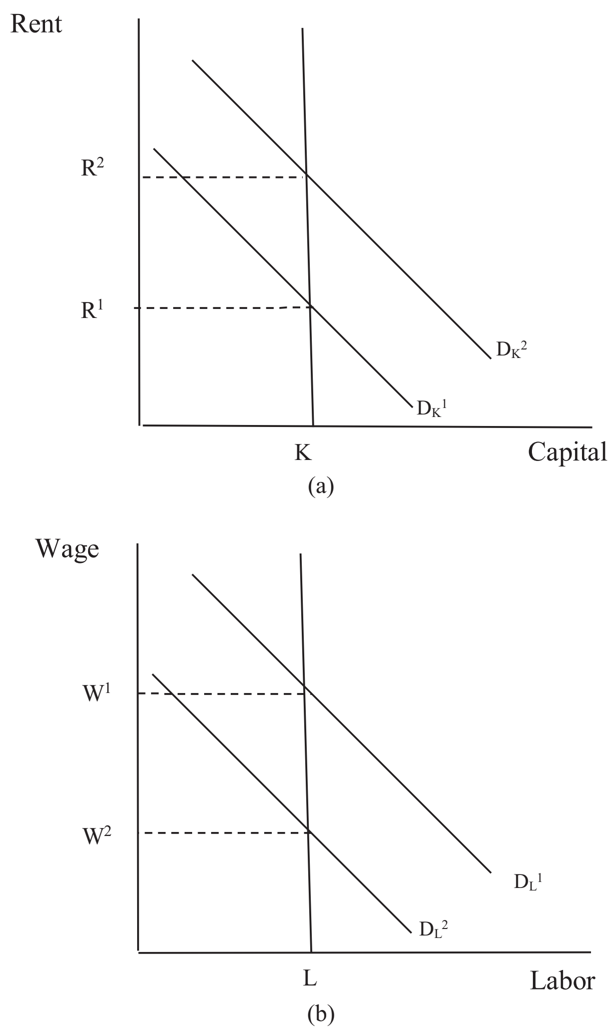


Figure 7.2. (a) Increase in economy-wide demand for capital due to an increase in the world price of the capital-intensive good. (b) Decrease in economy-wide demand for labor due to an increase in the world price of the capital-intensive good.

We depict these changes in the economy-wide demand for capital and labor in Figures 7.2a and 7.2b. In the figures, K describes the economy's supply of capital and L describes its supply of labor. Both supply curves are vertical, because we assume fixed endowment quantities that are fully employed. In the initial equilibrium in Figure 7.2a, D_K^1 is the demand for capital and R^1 is the initial equilibrium rental rate. A shift in industry structure toward the capital-intensive industry increases the economy-wide demand for capital to D_K^2, causing the rental rate to increase to R^2. In the initial equilibrium in Figure 7.2b, D_L^1 is the demand for labor and W^1 is the equilibrium wage. The shift in the country's industry structure toward the capital-intensive good causes the economy-wide demand for labor to fall to D_L^2 and the wage to decline to W^2.

We can use the Stolper-Samuelson theorem to understand the results of CGE model experiments that change world prices. As an example, we use the GTAP model with the U.S. 3×3 database to run an experiment that increases the world price of manufacturing by 10%. Based on our structure table in Chapter 3, we already know that U.S. manufacturing is relatively labor intensive when compared to agriculture, and that agriculture is intensive in the use of land, which is not used in manufacturing production. We might therefore expect that the increased world price of the manufactured good will lead to an increase in the U.S. wage relative to land rents.

In our experiment, we find that that the production mix in the United States shifts toward manufacturing. Manufacturing output increases 4.1% whereas agricultural production declines 2.6%. The shift toward production of a labor-intensive product causes the U.S. wage to increase 7.7% and the rental rate on land to decline 6.7%. The results are consistent with the predictions of the Stolper-Samuelson theorem.

Booming Sector, Dutch Disease

An increase in the world price of a country's export good would seem to offer it windfall benefits, but it can also lead to "deindustrialization," a problem that has received a great deal of attention from economists. This type of change in the production structure of an economy following an export boom has become known as *Dutch Disease* because it was first recognized by economists when it was experienced in the Netherlands following its discovery of natural gas. The process is described more generally by Corden and Neary (1982) as the effects of a booming sector on the rest of the economy. Their analysis of an increase in the world price of a country's export is of interest to CGE modelers because it illustrates both the effects of a terms-of-trade shock on the country's industry structure as well as macroeconomic feedback through real exchange rate appreciation. Both are general

Text Box 7.3. "Dutch Disease" in Cameroon

"The 'Dutch' Disease in a Developing Country: Oil Reserves in Cameroon" (Benjamin, Devarajan, and Weiner, 1989).

What is the research question? Rising oil and gas prices confer substantial wealth on exporters of natural resources, but these revenues can be a mixed blessing because they have the potential to cause deindustrialization, an unwelcome structural change known as "Dutch Disease." Most analyses of Dutch Disease have studied developed countries; how might a booming natural resource sector affect a developing country?

What is the CGE model innovation? The authors use a single-country CGE model of Cameroon that captures three key features of its economy: (1) agriculture, rather than manufacturing, is the traditional export sector; (2) manufactured imports are imperfect substitutes for domestic varieties (i.e., they assume an Armington import aggregation function); and (3) the oil sector is an enclave so that, except for generating income, it has weak links to the rest of the Cameroonian economy.

What is the experiment? A boom in Cameroon's oil export industry is simulated as a $500 million inflow of foreign savings – an amount equal to its foreign oil export earnings in 1982.

What are the key findings? Similar to the experience of developed countries, Cameroon's economy experiences a structural change when its oil sector booms. Because the oil sector is an enclave, structural change is due mostly to the spending effect, as higher oil revenues increase incomes and demand, instead of the resource movement effect that pulls resources into oil production. However, instead of the deindustrialization that characterizes Dutch Disease, it is Cameroon's traditional agricultural sector that contracts.

equilibrium effects that CGE models are well suited to analyze. (See Text Box 7.3.)

The Cordon-Neary model assumes a country with three sectors, capital that is fixed in each industry, and a labor force that is mobile among all three industries. Two sectors are traded – we'll call one of them oil (the booming sector) and the other manufacturing. The third sector is services (including products like haircuts and lawn care), which are not traded. The country is small, so the prices of its oil and manufacturing are set by world markets. The price of its services is determined by domestic supply and demand.

A boom in the price of its oil export has two effects. The *resource movement effect* describes the reallocation of productive resources toward the booming sector. The increase in the export price enables the export sector to attract labor from manufacturing and services by paying higher wages. The country's industry structure then changes as the booming sector expands and output of services and manufacturing falls. Hence, the country begins to deindustrialize.

The *spending effect* results from the income growth due to higher export earnings. Higher income causes consumer demand for both services and manufactured goods to increase. Demand growth for manufactures can be met by increasing imports at the fixed world price, but increased demand for services, which are not traded, can only be met by increasing domestic production. The spending effect therefore leads to further deindustrialization due to competition by the expanding services sector for the resources used in manufacturing.

Both the resource movement effect and the spending effect lead to real exchange rate appreciation. The real exchange rate is the price of domestic services (a non-traded good) relative to manufactures (a traded good with a fixed world price). The fall in the supply of services in the resource movement effect creates a scarcity that causes the price of services to rise relative to the price of manufacturing. The spending effect leads to increased demand for services and an additional increase in the price of services relative to manufacturing. Because exchange rate appreciation makes imports more affordable, the appreciation linked to the spending and resource effects also contributes to increased imports and the decline in production of manufacturing.

To explore the Dutch Disease effects of a change in world prices in a CGE model, we use the GTAP CGE model with the U.S. 3×3 database to simulate a 10% increase in the world price of manufacturing (the booming sector). Our CGE model does not conform to all of the assumptions in the stylized model developed by Cordon and Neary. For example, our model includes intermediate demand, and there is two-way trade in all three goods, including services. Yet, the Dutch Disease framework remains useful because it informs us that the key effects of a boom (or bust) in world export prices are observed in changes in a country's industry structure, its real exchange rate, and trade.

Based on the Dutch Disease model, we offer this prognosis for the U.S. economy. Output of U.S. manufacturing (the booming sector) will increase and agricultural output will decrease. However, the effect on output of services is ambiguous, because the spending effect will tend to increase its output, but the resource movement and exchange rate appreciation will tend to decrease its output. We also expect that the U.S. real exchange rate will appreciate, causing foreign demand for all U.S. exports to fall and U.S. demand for all imports to rise.

Results, reported in Table 7.8, show evidence of "disease" – the structural change that crowds out production in the nonbooming sectors. Output in the booming U.S. manufacturing sector increases, but output falls in both agriculture and services. The real exchange rate appreciates 7.4%. U.S. import demand therefore increases for agriculture and services, but note that manufacturing imports fall. This is because the higher world import price causes

Table 7.8. *Dutch Disease: Effects on United States of a 10% Increase in the Rest-of-World Price of Manufacturing (% change from base values)*

	Production (*qo*)	Imports (*qiw*)	Exports (*qwx*)
Agriculture	–2.6	13.9	–19.9
Manufacturing	4.1	–3.5	15.1
Services	–0.8	13.7	–21.6

Source: GTAP model, GTAP v.8.1 U.S. 3×3 database.

U.S. consumers to shift their demand toward the cheaper, domestic variety of manufactured goods. Exports of both agriculture and services fall because lower domestic production reduces the supply available for exports, and because exchange rate appreciation reduces foreign demand.

Trade Margins in International Trade

Many multi-country CGE models and their underlying SAM databases explicitly account for the *trade margin* costs incurred in international trade. These costs include land, air, and sea freight costs, plus insurance and any other handling charges that are required to ship goods from the exporter's port to that of the importer. Trade margins drive a wedge between the price received by the exporter and the price paid by the importer, and therefore can affect the quantity of trade. For example, the substantial decline in shipping costs since the 1950s is considered to be an important factor in explaining the rapid expansion of global trade over the past several decades.[4] There also can be shocks to shipping costs, which multi-country CGE models are well suited to analyze. For example, Sullivan (2010) studied the effects of piracy off the East African coast, which raised insurance and shipping costs for some commodities traded between certain partners. Jabara, et al. (2008) analyzed the bilateral trade effects of costly U.S. restrictions on the use of wood pallets to prevent the transoceanic introduction of invasive pests.

The effects of trade margins on the quantity and prices of traded goods are illustrated in Figure 7.3. In the figure, S is the small country's supply curve for production of the domestic variety, and D is its demand curve for the composite good, which is an aggregate of the domestic and imported varieties. Absent any margin costs, the country produces QO^1 and imports quantity $Q^1 - QO^1$ at a world price of PFOB. However, the introduction of trade margin costs increases its import price from PFOB to PCIF, causing

4 Hummels (2007), for example, found that U.S. air shipping costs declined by more than 90% between 1955 and 2004, and ocean transport costs fell from 10% to 6% of import values over the past 30 years.

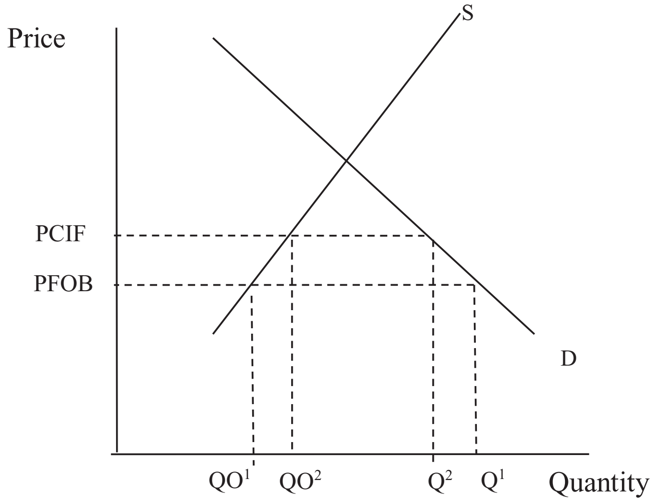


Figure 7.3. Import demand with trade and transport costs.

domestic production to increase to QO^2 and reducing the import quantity to $Q^2 - QO^2$. A shock that causes a change in the size of the trade margin cost per unit, PCIF – PFOB, thus affects production and import quantities.

We explore the role of trade and transport margins in a CGE model by using the GTAP CGE model and the U.S. 3×3 database to run an experiment that reduces the margin costs on all U.S. imports. First, consider the initial import margin costs reported in the U.S. 3×3 SAM and replicated in Table 7.9. Margin services increase the *cif* cost of agricultural imports by

Table 7.9. *Effects of a 10% Decline in Trade Margin Costs on U.S. Imports*

	Agriculture	Manufacturing
Base data		
Imports at *fob* price	28	1,797
Imports at *cif* price	33	1,878
Trade margin cost	5	81
Trade margin rate	17.8	4.5
10% increase in productivity in trade margins (*atd*)		
U.S. import price *pcif* (% change)	–0.18	–0.09
U.S. import quantity *qiw* (% change)	2.67	0.79
U.S. production quantity *qo* (% change)	–0.21	–0.11
ROW export price *pfob* (% change)	0.02	0.00

Note: Trade margin rate is the trade margin cost as a percent of the *fob* value of imports.
Source: GTAP model, GTAP v.8.1 U.S. 3×3 database.

17.8% relative to their *fob* cost and increase the cost of manufactured imports by 4.5%. Margin services are only required for trade in goods, not in services.

We model a reduction in the cost of trade margins as a 10% increase in productivity in trade margin services used for U.S. imports. This lowers the U.S. *cif* import prices for both goods, causing their import quantities to increase and their domestic production to fall. Notice that in our multi-country CGE model, the exporters' *fob* prices increase as a result of higher U.S. import demand, so U.S. *cif* import prices do not fall by the full amount of the reduction in margin costs. The benefits from the fall in margin costs therefore are split between the importer (the United States) and the exporter. The division of benefits of lower margin costs (or the burden of higher margin costs) between exporters and importers depends on the relative elasticities of the exporter's supply and the importer's demand.

Summary

Trade data in the SAM report trade valued in *fob* prices, import tariffs, export taxes, and the trade margin costs used in the international shipment of goods. Our discussion of trade behavior in a CGE model began by defining two concepts: the exchange rate and the terms of trade. The treatment of exchange rates differs among CGE models. The terms of trade measure a country's export prices relative to its import prices and describe the purchasing power of a country's export earnings. Terms of trade are thus a component in measuring changes in a nation's welfare. We used trade theory to ground our analyses of trade shocks in our CGE model. First, we relied on the Rybczynski theorem to explain the effects of an increase in a factor endowment on the commodity composition of trade and the subsequent effects on the terms of trade. The Stolper-Samuelson theorem informed our analysis of the effects of a change in world prices on a country's industry structure and factor prices. Our study of Dutch Disease explored a common problem in the world economy, in which a country experiences a change in its terms of trade (a boom or a bust for its main export) that causes changes in its industry structure. Finally, we explained how changes in trade margin costs affect trade volumes and world prices.

Key Terms

Dutch Disease
Heckscher-Ohlin theorem
Large country

Nominal exchange rate
Real exchange rate
Resource movement effect
Rybczynski theorem
Small country
Spending effect
Stolper-Samuelson theorem
Terms of trade
Trade margin

PRACTICE AND REVIEW

1. Suppose that technological innovation increases a country's capital productivity. It has two industries with the characteristics shown in Table 7.10:
   a. Which sector is capital intensive and which is labor intensive?
   b. How will the production costs of each sector be affected by an increase in capital productivity? Explain why.
   c. Which sector is exportable and which is importable?
   d. How do you expect imports and exports to be affected by the increase in capital productivity? How will this change in trade be likely to affect the terms of trade?

Table 7.10. *Industry Characteristics*

Industry	Capital Quantity	Labor Quantity	Production Quantity	Export Share of Production	Import Share of Consumption
Wine	142	1220	100	.50	.10
Televisions	97	25	100	.25	.40

2. Venezuela is a developing country that derives much of its export earnings from oil. Use the Dutch Disease framework to explain the possible effects on production and trade of its nonoil industries following a sudden hike in global oil prices. What are the public policy issues that your analysis raises for Venezuelan policy makers?

Table 7.11. *Terms-of-Trade Exercise*

	U.S. Corn Exports		U.S. Oil Imports	
	Brazil	China	Saudi Arabia	Canada
Percent change in price	6	4	4	1
Market share	.6	.4	.8	.2

3. Assume that a shock in world markets results in the price changes described in Table 7.11. Using the information on market shares, calculate the percentage changes in (1) the trade-weighted U.S. world export price, (2) the trade-weighted U.S. world (*fob*) import price, and (3) its terms of trade. Has the U.S. terms of trade improved or deteriorated?

8

Taxes in a CGE Model

This chapter examines the treatment of trade and domestic taxes in a computable general equilibrium (CGE) model. Trade taxes are imposed on imports and exports of goods and services. Domestic taxes are taxes paid by production activities on output and factor use and by purchasers on sales of intermediate and retail goods, and income taxes. We trace the tax data in a Social Accounting Matrix (SAM) to describe the agent and the economic activity on which the tax is levied and the amount of revenue generated by each tax; we also show how to use the SAM's data to calculate tax rates. Partial equilibrium diagrams then illustrate the theoretical effects of taxes on economic activity and welfare. The results of tax policy experiments using a CGE model support the theoretical predictions and offer insight into the economy-wide effects of each tax. Three applied examples of tax policy analysis explore the second-best welfare effects of a tax, the marginal welfare impacts of a country's entire tax structure, and the elimination of import tariffs in a preferential trade agreement.

The large federal deficit in the United States has spurred intense debate on whether the sizeable tax cuts enacted by the previous administration should be maintained or allowed to lapse. The tax cuts were intended to spur consumer demand during the financial crisis. Economists argued that lower taxes would lead to increased consumer spending, thereby providing an economic stimulus as production and employment expanded to meet higher demand. Some economists also argued that lower tax rates motivate producers to invest and produce more, which also helps stimulate employment. Taxes influence the behavior of an economy's consumers and producers in important ways. CGE models have proven to be a valuable tool for researchers in empirically and comprehensively analyzing how taxes affect households' and firms' economic decisions about how much to consume, produce, and trade, and how these actions impact the economy as a whole.

Governments impose taxes for many reasons. Foremost is the need to raise revenue to support the provision of public goods such as national defense and education. Governments sometimes use taxes to redress market failures such as externalities. For example, the government may impose carbon taxes to reduce the harm to public health that is associated with air pollution by private industry. Governments may impose "sin taxes" on goods or activities such as alcohol, tobacco, and gambling to discourage private behaviors deemed to be socially offensive or costly. Most governments tax imports to protect or promote selected industries, and sometimes they tax exports. Governments also use taxes to achieve societal goals, such as income equality. In this case, governments redistribute income by imposing high taxes on high-income households while giving tax credits or income transfers to low-income households.

Taxes impose burdens on the private sector. The *direct burden* of a tax is the amount of tax revenue that it generates. A 5% sales tax on groceries, for example, imposes a direct burden of five cents for every dollar spent on groceries. The direct burden of taxation is not a loss to the economy because each tax dollar is a transfer of spending power from the taxpayer to the government, absent any administrative costs.

Taxes deserve special scrutiny because they often lead to an *excess burden*, which is the loss in economic efficiency when producers and consumers change the quantities that they produce or consume in order to avoid paying a tax. For example, the 5% sales tax on groceries may cause consumers to buy fewer groceries and more of other, untaxed goods that they enjoy less. The change in their consumption bundle is inefficient, given the nation's productive resources and consumer preferences. The inefficiencies caused by tax-distorted consumption and production are an excess burden of taxes that is above and beyond the direct burden of paying the tax. Economists call these inefficiencies a *deadweight loss* because these foregone opportunities are not recouped elsewhere in the economy.

CGE models are especially useful for tax policy analysis because they can quantify both the direct (tax revenue) and excess (efficiency effects) burdens of taxes. Because the models are economy-wide, they also capture potential interactions among all taxes in an economy. This is important because governments typically impose many types and levels of taxes at the same time. Sometimes a tax or subsidy is actually beneficial, in the sense that it offsets the inefficiencies caused by another tax. For example, the introduction of a production subsidy to manufacturers may offset efficiency losses that result from a sales tax on their purchases of inputs. Of course, the overall impact of taxes on an economy also depends on the gains to society from the government spending that is funded by the tax. Keep in mind that societal gains, such as national security or cleaner air, are not readily monetized or generally accounted for in a typical CGE model, unless the economist adapts the model for that purpose.

We categorize taxes into five broad types for the discussion that follows:

- *Trade taxes* are levied on imports and exports.
- *Production taxes* are paid by production activities based on their output.
- *Sales taxes* are paid by domestic firms on their intermediate input purchases, and by consumers and investors on their purchases of final goods and services.
- *Factor use taxes* are paid by production activities based on their factor inputs.
- *Income taxes* are paid by factors or households based on income earned from wages and rents.

The first four taxes are *indirect taxes* because they are levied on the production or purchase of goods or factors. By comparison, *direct taxes*, primarily income taxes, are levied on factors or individuals. Indirect taxes are also distinguished from direct taxes because their burden potentially can be shifted onto someone else, which is not possible with direct taxes. *Tax incidence* describes how the burden of paying for indirect taxes is shifted between buyers and sellers after prices and wages adjust. For example, when a firm pays a tax to the government based on the value or quantity of its output (a production tax), the tax burden may be shifted, in whole or in part, to consumers, by charging higher retail prices. Individuals cannot similarly shift their income tax burden to others.

For each of the five taxes, we first trace the relevant data in the SAM. A review of the tax data is a useful starting point for any CGE-based tax analysis because the SAM identifies the agent in the model who pays the tax and the production or consumption decision on which the tax is assumed to be levied. For example, a tax on land use that is reported in agriculture's production activity column is paid by the producer, and it increases farmers' costs of production. Raising or lowering that tax will directly affect producers' level of output (shifting their supply curve left or right). However, if that same land tax is instead recorded as an expense in the land factor's column, then it is a direct tax, much the same as a poll tax. Raising or lowering the tax will mostly affect households' after-tax income and consumer demand. Placement of tax data in the SAM therefore reveals a great deal about how the tax is assumed to affect economic activity in the CGE model. Economists sometimes have stiff debates over how to represent a particular tax in a CGE model because this decision, similar to model closure rules, predetermines model outcomes.

We focus next on the economic analysis of taxes in a CGE model. We begin by developing simple partial equilibrium theories on taxation that help us formulate our expectations about the effect of each tax in our general equilibrium model. Graphical analyses of trade taxes include their terms-of-trade effects, but analyses of other taxes assume closed or small economies, with no terms-of-trade changes. These graphical analyses emphasize the direct burden (tax revenues) and the excess burden (the efficiency losses) associated with most taxes. The excess burdens appear in the graphs as "Harberger triangles," named after the economist, Arnold Harberger (1964), who refined this approach to measuring the efficiency waste caused by taxes.

With this foundation in data and theory, we are equipped to explore the effects of each type of tax in a CGE model. We start by creating a small-dimensioned pedagogical model, called TaxToy, that we use to provide a baseline or benchmark for our analysis of a tax. TaxToy is a GTAP CGE model with a tax-free version of the U.S. 3×3 database.[1] A distortion-free base model allows us to isolate the effects of each tax without the complexities that its interactions with other taxes in the economy can introduce. We then introduce each individual tax as a shock to this model and compare the model results to our theoretical predictions. Our discussion of model results focuses first on those variables that we highlight in our partial equilibrium analyses. Then, we consider selected general equilibrium results. Although these differ somewhat for each tax, we generally emphasize changes in the commodity composition of consumer baskets, industry output and trade flows, and in the terms of trade and national welfare (see Text Box 8.1).

Last, we undertake three examples of applied tax policy analysis. In the first two examples, we return to our GTAP CGE model with the original U.S. 3×3 database, in which there are many existing tax distortions. Tax experiments using this model allow us to explore the interaction among taxes that lead to second-best outcomes and the marginal welfare effects of the complex U.S. tax system. In a third applied example, we use the GTAP CGE model with a three-region database, named PTAToy, to study the welfare impacts of an elimination of bilateral trade taxes in a preferential free-trade agreement (PTA) between two of the three regions.[2]

[1] We create the distortion-free TaxToy CGE model using GTAP's Altertax utility to update all U.S. taxes and subsidies in the U.S. 3×3 v8.1 database to zero. We also change the default parameters assumption in the GTAP model to set RORDELTA to zero. This assumption means that net investment in all regions changes by the same proportion as the change in global savings, which allows regional rates of return to capital to vary. This simplifying assumption clarifies our analysis of tax policy by reducing the influence of global investment flows on experiment results. The TaxToy model used in this chapter is available for download from the GTAP Web site at: www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=4841

[2] The PTAToy model used in this chapter is available for download from the GTAP Web site at: www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=4841

Text Box 8.1. Welfare Decomposition in the GTAP Model

Decomposing Welfare Changes in the GTAP Model (Huff and Hertel, 2000; McDougall, 2003).

The GTAP model contains a utility developed by Huff and Hertel (2000) and McDougall (2003) that decomposes the total, equivalent variation welfare effect of model experiments. The welfare effect is a money metric measure of the value of the effects of price changes on real consumption and savings in a region. Its decomposition allows a researcher to identify welfare contributions by commodity, factor, and tax type and to account for terms-of-trade effects. The GTAP welfare decomposition describes these six components:

- *allocative efficiency effect* – the excess burden of each tax;
- *endowment effect* – due to changes in quantities of factors of production (e.g., labor and capital), which change an economy's productive capacity;
- *technology effect* – due to changes in the productivity of factors and/or intermediate inputs, which change an economy's effective endowments and productive capacity;
- *commodity terms of-trade effect* – due to changes in the economy's world (*fob*) prices of exported goods and services relative to its world (*fob*) prices of imported goods and services;
- *investment-savings terms-of-trade effect* – due to a change in the price of domestically produced capital investment goods relative to the price of savings in the global bank; and
- *preference change effect* – due to changes in the shares of private consumption, government, and savings in national spending.

Trade Taxes

Import Tariffs

Import tariffs are taxes that are levied on the quantity or value of imported goods and services. Import tariffs are levied in one of two ways. *Specific* tariffs are paid per unit of import, such as $1 dollar per barrel of oil. Specific tariff payments grow in proportion to quantity, so that the import tariff on two barrels would cost $2 dollars and the tariff on three barrels would cost $3 dollars, and so on. Specific tariff payments do not change when prices change; for example, the importer pays $1 dollar per barrel regardless of whether oil costs $25 or $125.

Ad valorem tariffs are levied as a percentage of the *cif* import value (which includes trade margin costs). For example, a 5% ad valorem import tariff on a handkerchief with an import value of $1 increases its cost to $1.05. If the hanky's *cif* import value increases to $2, its cost, including the tariff, would be

Table 8.1. *Import Tariffs and Imports from the U.S. 3×3 SAM*

Data in $U.S. Billion or Percent	Agriculture	Manufactures	Services
Import tariff revenue	0.52	23	0
Imports (value in *fob* prices)	28	1,797	315
Import trade margins	5	81	0
Import tariff rate	1.6	1.2	0.0

Source: GTAP v.8.1 U.S. 3×3 SAM.

$2.10. In this case, tariff revenue for the single handkerchief increases from five cents to ten cents following the change in its price.

Import tariffs are paid by the import varieties of the commodity columns of the SAM to the import tariff row account. The tariff increases the cost of imported goods so all categories of intermediate and final demand that consume imports ultimately pay the tariff. Table 8.1 reports the import tariff revenue and the value of imports from the U.S. 3×3 SAM. We calculate ad valorem import tariff rates as:

$$\text{import tariff revenue}/\textit{cif} \text{ value of imports} * 100.$$

The U.S. ad valorem tariff rate on manufacturing is therefore:

$$\$23 \text{ billion}/(\$1{,}797 \text{ billion} + \$81 \text{ billion}) * 100 = 1.2\%$$

The U.S. tariff rate is highest on imports of agricultural goods (1.6%) and lowest on services (zero). Figure 8.1 illustrates the economic effects an ad

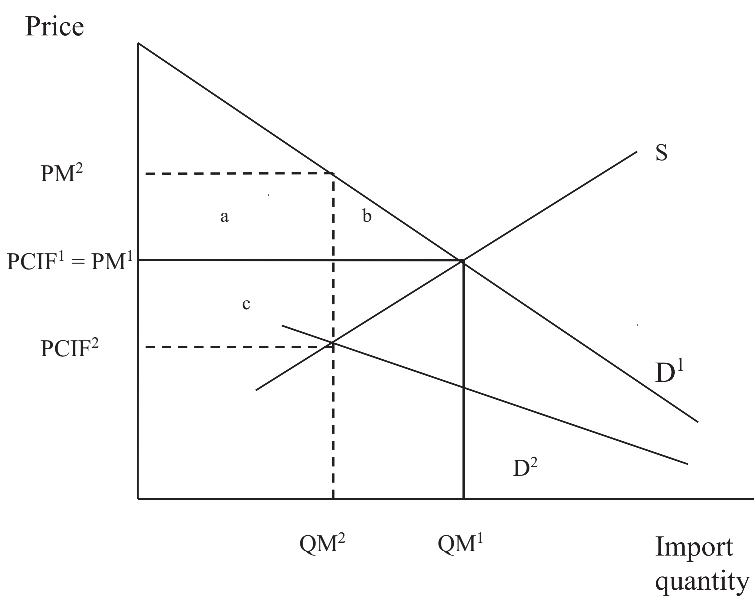


Figure 8.1. Effects of an ad valorem import tariff on the importer.

valorem import tariff on a large economy. In the figure, S describes the foreign supply of the imported good. Given the Armington assumption that goods are differentiated by country of origin, there is no domestic production of the imported variety. D^1 is a compensated demand curve that describes the duty-free demand for imports by domestic consumers.[3] In the initial market equilibrium, the *cif* price of imports is $PCIF^1$. Assuming zero trade margin costs, it is equal to the exporter's *fob* price. In the initial equilibrium, $PCIF^1$ is equal to the consumer import price PM^1 and quantity QM^1 is imported.

The introduction of an import tariff adds an additional cost, to the import price, which rotates the demand curve downward to D^2. In the new equilibrium, consumers pay a higher domestic price of PM^2; the import quantity declines to QM^2; and the *cif* import price net of the tariff falls to $PCIF^2$.

The tariff has three effects on the importing country. The direct burden of the tariff, shown as area $a + c$, is the amount of tariff revenue paid by consumers to the government on imports of quantity QM^2. Tariff revenue redistributes purchasing power from consumers to the government, so this area is not a loss to the economy.

The second effect is the excess burden on the importer, shown as area *b*. It represents a consumption inefficiency, because consumers who would have been willing to purchase $QM^1 – QM^2$ imports at the free market price no longer can do so. The difference between the price that consumers are willing to pay and the market price is the consumer's "surplus." For example, at QM^2, a consumer who would have been willing to pay PM^2 actually paid only PM^1 at free-trade prices, and so gained a surplus on that unit of $PM^2 – PM^1$. The sum of the surpluses enjoyed by consumers on all units up to QM^1, purchased at free trade prices, is the triangular area between PM^1 and D^1. The trapezoid formed by areas *a* plus *b* is the sum of the consumer surplus that is lost when consumers reduce their import consumption to QM^2 and pay the higher price of PM^2. Because the foregone surplus shown by area *a* is transferred to the government as a part of the tax revenue, the remaining area, *b*, is the loss in consumer surplus that is not recouped elsewhere in the economy. The tariff has no effect on production efficiency because there is no domestic production of the imported variety.

[3] This type of demand curve implies that the government compensates consumers dollar for dollar for their tariff expenditure, either through a lump-sum transfer of income or other mechanism. This compensation assumption is common in tax policy analysis. It allows economists to attribute all quantity changes to the substitution effect (which is the excess burden) because the compensation cancels any income effects of the tax. In other words, this approach keeps the consumer on the same indifference curve by holding income constant and describes only the substitution along the curve when the tax changes relative prices. See Ballard and Fullerton (1992) for a survey of this approach in the economics literature

For large countries, there may also be a terms-of-trade effect as described by area *c*. Our example in Figure 8.1 shows a terms-of-trade gain for the importer because the decline in its import demand causes the *cif* import price, excluding the tariff, to fall from $PCIF^1$ to $PCIF^2$ on quantity QM^2 of imports. The size of its terms-of-trade gain depends in part on the slope of the import supply curve. In general, the lower the foreign export supply elasticity (i.e., the steeper the slope of the import supply curve), the larger the importer's terms-of-trade gain from a tariff. If the importing country is too small in the exporter's market to affect its export price, then the foreign supply curve is horizontal. In this case, the import price remains at $PCIF^1$ and there is no terms-of-trade effect.

The terms-of-trade effect, like the direct burden, redistributes purchasing power. In this case, purchasing power is redistributed from foreigners to domestic consumers. In effect, the lower price accepted by foreigners compensates consumers for area *c* of their tariff payment to the government because the domestic import price (PM^2) increases by less than the full amount of the tariff. The terms-of-trade gain to the importer, area *c*, is a loss of import-purchasing power by the exporting country.

Because tax revenue simply redistributes national income, the change in national welfare includes only the excess burden, or efficiency effect, of the tariff plus its terms-of-trade effect. Therefore, the net effect on the importer's welfare depends on whether its consumption efficiency loss, shown by area *b*, is greater than its terms-of-trade gain, area *c*. The effect on the exporter's welfare is unambiguously a loss, shown by its terms-of-trade decline, area *c*.

The figure also illustrates how tariffs diminish global welfare. The loss in global welfare is the sum of countries' efficiency losses, shown in our case as the importer's area *b*. Terms-of-trade effects are not included in a measure of global welfare. Because one country's terms-of-trade loss is equal to its partner's terms-of-trade gain, this price effect just redistributes purchasing power among countries, similar to the domestic redistribution of tariff revenue. Redistribution does not affect global welfare as long as we assume – as we do in standard CGE models – that income has the same value, regardless of its distribution among consumers, governments, or countries. In a more sophisticated analysis, we might choose to relax this assumption to reflect different valuations across market participants, depending, for example, on their initial levels of income. Arguably, another dollar might mean more to consumers in countries with very few dollars to start with than it does to someone who has a great many.

By studying the theory of import tariffs before we carry out a CGE model experiment we can identify the results that are most relevant to consider and to report in our discussion, and we can develop expectations about their direction of change. With this foundation, we are ready to study a

Table 8.2. *Effects of a 15% Import Tariff on Manufacturing Imports to the United States*

U.S. manufacturing	
Tariff revenue ($U.S. billion) (NETAXES)	206.7
Import quantity (*qiw*) (% change)	– 19.1
Bilateral export price from ROW (% change) ($pfob_{ROW}$)	– 1.0
Terms of trade (% change) ($pfob_{US,ROW}$–$pfob_{ROW,US}$)	6.2
Domestic consumer price of import (% change) (*pim*)	13.9
Efficiency effect (U.S. $billion)	– 22.2
Welfare ($U.S. billion)	
U.S. welfare	80.6
U.S. terms of trade	102.9
Rest-of-world welfare	– 10.6
World welfare	– 24.9
Selected general equilibrium effects in United States (% change)	
Bilateral export price of mfg. to ROW ($pfob_{US,ROW}$)	5.2
Real exchange rate (*pfactor*)	3.5
Exports of agriculture (*qxw*)	– 11.6
Exports of manufactures (*qxw*)	– 34.3
Exports of services (*qxw*)	– 15.6

Source: TaxToy CGE model with distortion-free U.S. 3×3 v.8.1 database.

CGE analysis of the introduction of an import tariff in one industry. Our experiment is the introduction of a 15% import tariff by the United States on imports of manufactures. For this and most other tax experiments, we use the TaxToy CGE model, in which all taxes in the U.S.3×3 database have been removed.

Results of the import tariff experiment, reported in Table 8.2, are consistent with the qualitative results shown in Figure 8.1. A contribution of our CGE model analysis is that it enables us to quantify these impacts. The tariff's direct burden is the import tariff revenue for the U.S. government of $207 billion. The quantity of U.S. manufacturing imports falls by 19%, contributing to a terms-of-trade gain for the United States as the rest-of-world's *fob* export price of manufactures falls by 1%. As a result, the 13.9% increase in the domestic consumer price of manufactured imports is less than the full amount of the tariff. The excess burden, or deadweight efficiency loss, related to manufacturing totals $22 billion dollars.

Our CGE analysis also takes into account general equilibrium effects that lie outside the scope of our theoretical, partial equilibrium model. First, we consider the manufacturing terms-of-trade effect. Recall from our discussion in Chapter 6 that the terms of trade depend on changes in both the import and export prices. Our CGE-based analysis finds that the U.S. import tariff increases domestic demand for the U.S. variety, which reduces the supply available for export. U.S. manufactured exports to the rest of the world fall by 34.3% and their price increases 5.2%. Thus, changes in *both* the U.S. import and export prices account for the 6.2% improvement in the U.S. terms of trade in manufactures.

The import tariff on manufactured goods affects U.S. industry structure because an expanding manufacturing sector competes with other industries for productive resources. This competition causes U.S. wages and rents to rise and increases U.S. factor prices relative to those in the rest-of-world. This is similar to a real exchange rate appreciation and it makes all U.S. goods relatively expensive on world markets. Both resource competition and real appreciation contribute to a decline in U.S. production and exports of agriculture and services, and an increase in U.S. imports of these goods. These changes in trade flows also contribute to the aggregate U.S. terms-of-trade gain of $102.9 billion and a total U.S. welfare gain of $80.6 billion. The $10.6 billion decline in the rest-of-world's welfare results from its terms-of-trade losses; because there are no taxes in that region, there can be no efficiency effects due to this experiment. Global welfare, which measures the global sum of efficiency losses due to the tariff, declines by $24.9 billion.

Export Taxes

Countries sometimes impose export taxes to raise revenue from exportable industries such as mining, or to ensure that adequate supplies of vital goods, such as foodstuffs or strategic minerals, remain available for the home market. Export taxes lower the price received by the producer on sales to the world market. An export tax therefore encourages producers to shift their sales from the export market to the domestic market – or to shift into the production of other goods and services.

Export taxes are reported in the SAM as an expenditure from the domestic variety of the commodity column account to the export tax row. Exports in *fob* prices, which include export taxes, are reported in the rest-of-world column account as a purchase from the domestic commodity account row. Data in the U.S. 3×3 SAM report an export tax of $3 billion on U.S. manufacturing exports of $970 billion.

We calculate the export tax or subsidy rate as:

$$\text{Export tax evenue/value of export in world } \textit{fob} \text{ price} * 100$$

For example, the export tax rate on U.S. manufacturing exports is:

$$\$3/\$970 \text{ billion} * 100 = 0.3\%$$

Figure 8.2 illustrates the market effects of an ad valorem export tax. Although the graph looks similar to Figure 8.1, note carefully that the definitions of the supply and demand curves are different. In this case, S^1 describes the

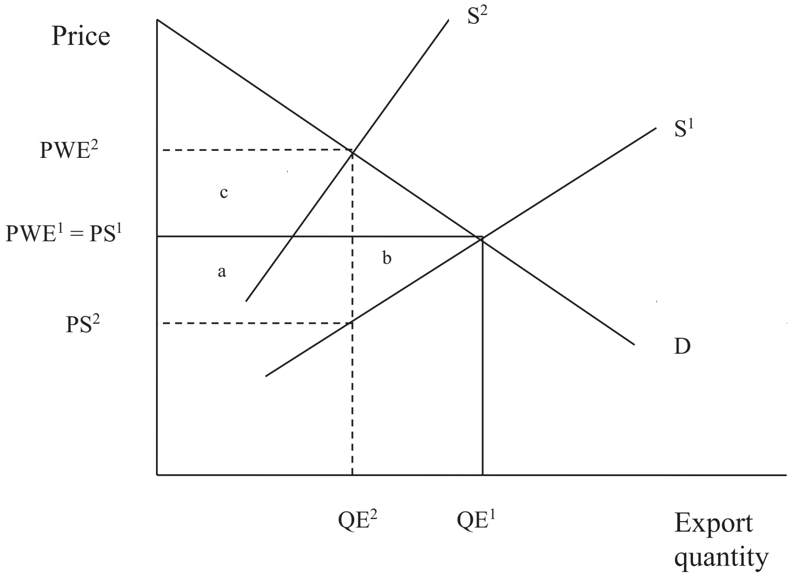


Figure 8.2. Effects of an ad valorem export tax on the exporter.

home country's supply of exports (QE) to the world market. Because we assume that products are differentiated by country of destination, there is no domestic demand for the export variety. D describes foreign demand for the home country's exports. In the initial equilibrium, quantity QE^1 is exported at the *fob* export price of PWE^1. In the absence of an export tax, PWE^1 is equal to PS^1, the producer's supply price. The introduction of an ad valorem export tax rotates the export supply curve backward to S^2. In the new equilibrium, export sales decline to QE^2, the export price increases to PWE^2, and the producer price declines to PS^2.

Similar to import tariffs, export taxes have three effects on the exporting country. The direct burden is the amount of export tax revenue that is transferred from producers to the government, shown as area $a + c$. The excess burden, or efficiency effect, in the exporting country is described by area b. Production is inefficient because the marginal cost of producing the foregone output $QE^1 - QE^2$, shown by the pretax supply curve, is less than the price that foreigners are willing to pay. Another way to think about it is that, before the tax, the marginal cost to produce QE^2 was PS^2 but producers sold it for PS^1, gaining a producer "surplus" for that unit of $PS^1 - PS^2$. The sum of these surpluses over all units of production up to QE^1 is total producer surplus, shown by the triangular area between PS^1 and S^1. The tax causes producers to lose producer surplus described by the trapezoid area of $a + b$. Area a is recouped by the government as tax revenue but area b is a deadweight loss, in excess of the tax burden, that is not recouped elsewhere in the economy. Notice that there is no consumption inefficiency because the export variety is not consumed domestically.

The third effect is the terms-of-trade gain, area *c*, which measures the redistribution of purchasing power from foreign consumers to domestic producers because the reduction in export supply causes the export price to rise from PWE^1 to PWE^2 on export quantity QE^2. This transfer compensates producers for part of their revenue transfer to the government; in effect, producers have passed on part of the export tax burden to foreign importers through an increase in their export price. In this case, we assume a large country exporter, consistent with the Armington assumption that every country is large country in its export market. A small country (as in many single-country CGE models) would face a horizontal world demand curve for its exports, and the producer's price would fall by the full amount of the export tax.

The net effect on the exporter's welfare depends on whether its efficiency loss, area *b*, is larger than its terms-of-trade gain, area *c*. The effect on the importing country's welfare is unambiguously a loss, shown by area *c.* The loss in global welfare is also unambiguously negative; it is the sum of all countries' efficiency losses, which in this case is area *b.*

To explore the effects of an export tax on one industry in a CGE model, we use the TaxToy CGE model with the distortion-free U.S. 3×3 database to run an experiment that introduces a 15% export tax on U.S. manufacturing. We find a direct burden, the export tax revenue, of $84.2 billion and an excess burden, the efficiency loss in manufacturing, of $35.8 billion (Table 8.3). The

Table 8.3. *Effects of a 15% Export Tax on U.S. Manufactures*

U.S. Manufacturing	
Tariff revenue ($U.S. billion) (NETAXES)	84.2
Efficiency effect (U.S. $billion)	– 35.8
Production (*qo*) (% change)	– 4.1
Export quantity (*qxw*) (% change)	– 47.1
Producer price (*ps*) (% change)	– 4.5
World export price ($pfob_{US,\ ROW}$) (% change)	12.3
Terms of trade (% change) ($pfob_{US,ROW} - pfob_{ROW,US}$)	10.0
Welfare ($U.S. billion)	
U.S. welfare	– 42.7
Rest-of-world welfare	– 6.5
World welfare	– 36.1
Selected general equilibrium effects in the United States (% change)	
Bilateral import price of mfg. from ROW ($pfob_{ROW,US}$) (% change)	2.3
Import quantity of manufacturing (*qiw*)	– 18.3
Export quantity of agriculture (*qxw*)	23.4
Exports quantity of services (*qxw*)	30.5
Real exchange rate (*pfactor*)	– 6.2

Source: TaxToy CGE model with distortion-free U.S. 3×3 v.8.1 database.

U.S. manufacturing output quantity falls by 4.1% and its export quantity falls 47.1%. The reduction in U.S. export supply yields a U.S. terms-of-trade gain in manufacturing. The U.S. *fob* export price increases nearly 13%, so the producer price falls by only 4.5%.

Our general equilibrium model yields additional insights into the effect of the tax. Because most are the mirror image of the effects of the import tariff, we leave it as an exercise for you to explain the effects of a decline in U.S. manufacturing production and exports on industry structure, trade flows, U.S. terms of trade, the real exchange rate, and U.S. and world welfare.

Production Taxes

Producers pay production taxes on the basis of the value or quantity of their output. These taxes are a part of their costs of production. For example, U.S. companies engaged in oil and natural gas production pay a wide variety of production-based taxes to state, federal, and local governments. These taxes raise their production costs. Production taxes can also be negative (i.e., subsidies). For example, many countries provide tax credits or direct subsidies based on the production of agricultural products.

In the SAM, the production activities' column accounts pay these taxes to the production tax row account. Table 8.4 displays these row and column accounts from the U.S. 3×3 SAM.

We calculate production tax rates (or subsidies) as:

$$\text{Production tax/gross value of production} * 100.$$

For example, the production tax rate for U.S. services is:

$$511/18,212 * 100 = 2.8\%$$

Figure 8.3a illustrates the market effects of an ad valorem production tax. In the figure, the initial market supply curve, S^1, describes domestic production, and the compensated demand curve, D, describes consumer demand. QO^1 is

Table 8.4. *Production Taxes in the U.S. 3×3 SAM ($U.S. billions)*

	Agriculture	Manufactures	Services
Production tax	0.7	70	511
Gross value of production	326	6,657	18,212
Production tax rate	0.2	1.0	2.8

Source: GTAP v.8.1 U.S. 3×3 database.

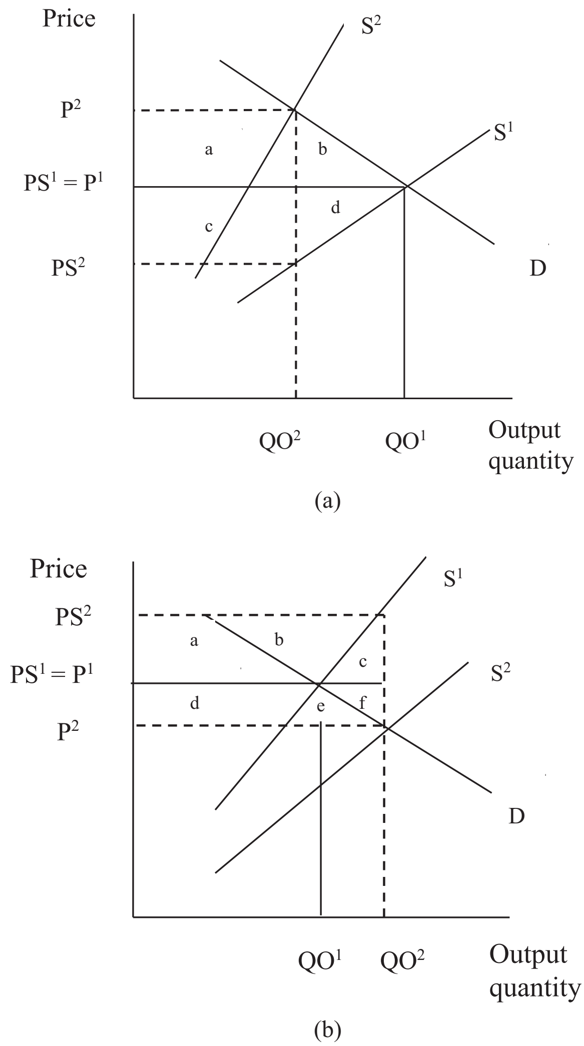


Figure 8.3. (a) Market effects of an ad valorem production tax. (b) Market effects of an ad valorem production subsidy.

the initial market equilibrium output quantity. In the absence of sales taxes, the initial producer price, PS^1, is equal to the initial consumer price, P^1. The introduction of an ad valorem production tax rotates the industry supply curve leftward to S^2. This results in a higher market equilibrium price, P^2, for consumers, a lower after-tax price for producers, PS^2, and a fall in the equilibrium quantity of supply and demand to QO^2.

The direct burden of the production tax is area $a + c$, which is the tax revenue paid by producers to the government. Areas $a + b$ are the loss of consumer surplus and areas $c + d$ are the loss of producer surplus due to the tax. Because areas $a + c$ are recouped by the government as tax revenue, the excess burden is the combined loss in consumption efficiency, area *b*, and production efficiency, area *d*.

Areas *a* and *c* also describe the incidence of the production tax. The figure illustrates that, although producers actually pay the tax, the burden of paying for it is shared with consumers because producers have been able to raise their (gross of tax) sales price from P^1 to P^2. As you can see from the figure, the size of the tax revenue and its incidence are determined by the slopes of the supply and demand curves, which in turn are determined by the elasticities of supply and demand. If demand is perfectly elastic (a horizontal demand curve), then the consumer price would remain at P^1 and producers would absorb the full cost of the tax. If supply is perfectly elastic (a horizontal supply curve), then consumers would absorb the full cost of the tax.

Many countries subsidize rather than tax their producers. The analysis of a production subsidy differs in some respects from the analysis of a tax. In Figure 8.3b, the introduction of an ad valorem production subsidy rotates the supply curve rightward to S^2. The new equilibrium output increases to QO^2, the consumer price falls to P^2, and the price received by producers increases to PS^2.

In the case of a subsidy, the direct burden falls on the government because the subsidy is a transfer from the government to producers, instead of tax revenue for the government. In the figure, government spending is the sum of areas $a + b + c + d + e + f$. However, the subsidy increases consumer surplus only by areas $d + e$ and increases producer surplus only by areas $a + b$. The increased quantity of production and consumption is inefficient because at quantities that exceed QO^1, the marginal benefit to consumers of each additional unit is less than the marginal cost of its production. This inefficiency is described by areas $c + f$, which is the excess burden of the subsidy.

With these insights from our partial equilibrium models, we turn to an examination of the effects of a production tax in one industry in our TaxToy CGE model. Our experiment is the introduction of a 15% production tax on U.S. manufacturing output. We find that the direct burden is the tax revenue of $868.9 billion and the excess burden is an $86 billion loss in efficiency due to a 16% decline in production and a 13% decline in consumption (Table 8.5). The 4.7% fall in the producer price and the 12.1% increase in the private household's price tell us that the tax burden has been shared between U.S. producers and consumers, but that most has been passed on to consumers.

Our CGE model also describes the general equilibrium effects of the tax. In the manufacturing sector, lower domestic production reduces its demand for factor inputs, causing economy-wide wages and rents to fall and the real exchange rate to depreciate. Manufactured exports decline sharply as production falls and the demand for manufactured imports increases, despite

Table 8.5. *Effects of a 15% Production Tax on U.S. Manufactures*

Manufacturing	
Production tax revenue ($U.S. billion) (NETAXES)	868.9
Efficiency losses in mfg. ($U.S. billion)	86.0
Production quantity (*qo*) (% change from base)	– 15.6
Domestic demand (*qds*)(% change from base)	– 12.9
Producer price (*ps*) (% change from base)	– 4.7
Private household consumer price (*ppd*) (% change from base)	12.1
Selected general equilibrium effects in the United States (% change from base)	
Wages (*pfe*)	– 18.2
Capital rents (*pfe*)	– 18.4
Real exchange rate	– 18.2
Manufacturing export quantity (*qxw*)	– 30.2
Manufacturing import quantity (*qiw*)	2.6
Agricultural production (*qo*)	5.1
Services production (*qo*)	3.4
Terms of trade in manufacturing ($pfob_{US,ROW} - pfob_{ROW,US}$)	5.9
U.S. welfare ($U.S. billion) (EV)	– 210.4

Source: TaxToy CGE model with distortion-free U.S. 3×3 v.8.1 database.

exchange rate depreciation, due to the higher domestic price. On net, these trade changes cause the manufacturing terms of trade to improve. Both lower factor input prices and the increase in foreign demand spurred by depreciation encourage agricultural and services production to increase. The total U.S. welfare effect, which combines its efficiency loss and overall terms-of-trade effects, is a loss of $210.4 billion.

Sales (and Intermediate Input) Taxes

Sales taxes are paid by domestic final demand (households, investment, and sometimes government) on purchases of commodities used for consumption or investment. Production activities pay sales taxes on their purchases of intermediate inputs. The sales taxes are a part of their cost of production. Foreigners do not pay other countries' sales taxes, so a country's exports do not generate sales tax revenue.

In many countries, sales tax rates vary by commodity and type of buyer. In the United States, for example, consumers usually pay sizeable sales taxes on their purchases of autos but often pay little or no sales tax on their grocery purchases. Private household consumers pay sales taxes on many products while sales taxes on these same goods are waived for entities like churches and other nonprofit organizations. Negative sales taxes, like other negative taxes in the SAM, denote subsidies. They reduce the cost of

Table 8.6. *Sales Taxes on U.S. Household Purchases of Domestically Produced Variety*

	Household
Purchases ($U.S. billion)	
Agriculture	53
Manufactures	1,355
Services	7,742
Sales tax ($U.S. billion)	
Agriculture	2
Manufactures	137
Services	51
Sales tax rate (%)	
Agriculture	4
Manufactures	10
Services	1

Source: GTAP v.8.1 U.S. 3×3 database.

a purchase. Some common examples of subsidies are food stamps, which low-income households can apply to their food purchases, or rebates on farmers' purchases of intermediate inputs, such as fertilizer.

The SAM reports sales taxes as a payment from the column account of the purchaser to the sales tax row account for each purchased good. As an example, Table 8.6 reports data from the U.S. 3×3 SAM on private households' sales taxes on their purchase of the domestically produced variety of each commodity. These total $190 billion ($2 billion + $137 billion + $51 billion) on purchases of agriculture, manufactures, and services.

Sales tax rates are calculated as the ratio of the tax to the pretax value of the sale:

$$\text{commodity sales tax/pretax value of commodity purchase} * 100.$$

For example, the tax rate on households' purchases of domestic manufactured goods is calculated as:

$$137/1{,}355 * 100 = 10.1\%$$

Firms' payment of a sales tax or their receipt of a subsidy on purchases of intermediate inputs are called an intermediate input tax or subsidy. The effects of input taxes or subsidies on the output of a firm are identical to those of a production tax or subsidy, shown in Figures 8.3a and 8.3b, so we do not reproduce that analysis here.[4]

[4] The effects are identical if we assume fixed Leontief intermediate input-output coefficients, which is a common assumption in CGE models

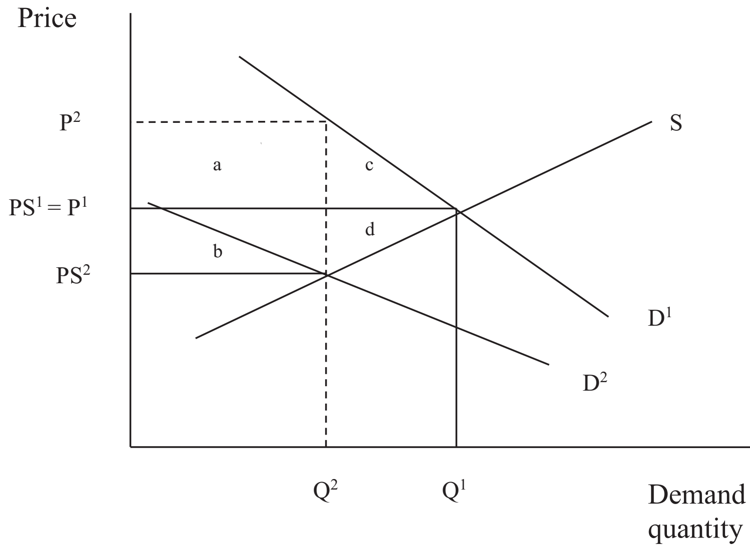


Figure 8.4. Effects of an ad valorem sales tax on the domestic market.

Figure 8.4 describes the effect of an ad valorem sales tax on the domestic supply and compensated demand for a final good, Q. In the figure, D^1 is the initial compensated demand curve and S is the supply curve for the domestic production of Q that is sold in the domestic market. Q^1 is the initial market equilibrium quantity. P^1 is the initial market equilibrium price for consumers and, in the absence of a sales tax, it is equal to the producer price of PS^1. The sales tax rotates the demand curve leftward to D^2. The new market equilibrium is at quantity Q^2 where consumers pay the tax-inclusive sales price of P^2 and producers receive price PS^2.

The direct burden of the tax is shown by area $a + b$, which is the amount of sales tax revenue collected by the government on sales of Q^2. Although the tax is paid by consumers, the figure shows that the burden is shared with producers due to the decline in the producer price to P^2. The excess burden of the tax, described by areas $c + d$, measures the loss in consumer and producer surplus as the market equilibrium quantity falls by $Q^1 - Q^2$. The decline in consumption and production is inefficient because the marginal benefit to consumers of each additional unit between $Q^1 - Q^2$ exceeds its marginal cost of production.

To explore the effects of a sales tax on one commodity in a CGE model, we carry out an experiment that imposes a 15% sales tax on households' purchases of the domestic variety of the manufactured commodity. We use the TaxToy CGE model with the distortion-free U.S. 3×3 database. We find that the direct burden of the sales tax is a tax revenue of $149.1 billion (Table 8.7). Its excess burden is an efficiency loss in manufacturing of

Table 8.7. *Effects of 15% Sales Tax Rate on U.S. Household Purchases of the Domestic Manufacturing Commodity*

U.S. Manufacturing	
Sales tax revenue ($U.S. billions) (NETAXES)	149.1
Efficiency loss ($U.S. billion)	16.5
Household consumption (*qpd*) (% change)	– 18.7
Production quantity (*qo*) (% change)	– 2.8
Consumer price (*pd*) (% change)	14.1
Producer price (*ps*) (% change)	– 0.8
Selected general equilibrium effects (% change from base)	
Household consumption of domestic agriculture (% change) (*qpd*)	0.7
Household consumption of domestic services (% change) (*qpd*)	0.9
Agricultural production (*qo*)	– 0.3
Services production (*qo*)	0.6
Manufacturing export quantity (*qxw*)	7.4
Manufacturing import quantity (*qiw*)	4.0
U.S. welfare ($U.S. billion)	– 38.2

Source: TaxToy CGE model with distortion-free U.S. 3×3 v.8.1 database.

$16.5 billion as both the quantity of production and household demand fall. The consumer price increases by nearly the full amount of the tax, but the producer price declines only slightly – indicating that U.S. consumers bear most of the burden of the tax.

Once again, we also consider selected general equilibrium effects of the tax. For this tax, we focus on the role of demand shifts in influencing industry structure. The sales tax changes the relative prices of consumer goods, causing private households to change the commodity composition of their baskets. When they reduce their consumption of domestic manufactures, they increase their consumption of domestically produced agriculture and services. Production in services increases. Agricultural output falls, however. A study of the input-output linkages in our SAM (Appendix A Table) helps explain why: most of the domestic agricultural product is used as an intermediate into U.S. manufacturing. The fall in manufacturing production causes demand for, and output of, U.S. agriculture to decline.

Trade flows are also an important part of this tax's impacts. On the import side, the sales tax on the domestic variety of manufactures causes the imported variety to become relatively cheaper, which increases the quantity of manufactured imports demanded by U.S. households. On the export side, the fall in U.S. demand for the domestic supply increases the quantity available for export, causing exports to rise. The changes in both trade flows contribute to a decline in the U.S. terms of trade in manufacturing. U.S. terms of trade in the other two sectors also fall as their production and export supply increase. Total terms-of-trade losses, combined with efficiency losses, cause U.S. welfare to decline by $38.2 billion because of the sales tax.

Factor Use Taxes

Producers pay taxes or receive subsidies based on the quantity of factors (e.g., labor, capital, and land) that they employ in their production process, or on the value of their factor payments. Data on factor use taxes are reported in the production activity column of the SAM as a payment to the factor use tax row. Factor tax rates are calculated for each factor in each industry as:

$$\text{factor tax/pretax factor payment} * 100.$$

We report these data for the agricultural and manufacturing activities from the U.S. SAM in Table 8.8. For example, in the U.S. 3×3 SAM, the factor tax rate for land used in agriculture is:

$$-1.5/36 * 100 = -4.1\%.$$

Note that the factor tax rate is negative, which means that U.S. farmers receive a subsidy on land use.

It is not unusual for different governmental entities within the same country to impose simultaneous factor use taxes and subsidies on the same factor. For example, landowners may pay a real estate tax to their state or local government and, if they are farmers using the land for agricultural purposes, they may also receive an acreage-based subsidy, based on the very same parcel of land, from the federal government. Thus, factor use tax data may report the combined costs of different tax programs.

Table 8.8. *Factor Use Taxes in the United States in Agriculture and Manufacturing*

	Agriculture	Manufacturing
Factor payment ($U.S. billion)		
Land	36	0
Labor	47	1,361
Capital	53	649
Factor use tax ($U.S. billion)		
Land	−1.5	0.0
Labor	3.8	205.0
Capital	−1.7	21.1
Factor use tax rate (%)		
Land	−4.1	0.0
Labor	8.2	15.1
Capital	−3.2	3.3

Source: GTAP v.8.1 U.S. 3×3 database.

Sometimes factor use taxes are uniform across industries, such as the Social Security tax that is paid as a percentage of wages by all employers in the United States. Uniform factor use taxes or subsidies do not influence the distribution of factor employment across industries. However, it is often the case that factor taxes differ among industries or by use, such as different real estate tax rates for commercial and residential zones. In the United States, for example, the 8.2% tax rate on labor used in agriculture, reported in Table 8.8, is lower than the 15.1% tax rate on labor employed in manufacturing. In this case, the different labor tax rates change the relative costs of production in the two industries, discouraging employment and production in the industry with the higher labor tax.

Factor use taxes also typically differ by factor. For example, an industry's corporate tax rate on capital services may be quite high relative to its payroll tax. Tax rates on land, labor, and capital in U.S. agriculture, reported in Table 8.8, illustrate this point. Agriculture's land and capital inputs are subsidized, but its use of labor is taxed. When factor use tax rates differ by factor then – if the production technology allows it – this too can lead to a misallocation of factors. Those factors whose employment is taxed will be underused and those factors that are subsidized will be overused relative to their most efficient level of employment in each industry.

The effect of a factor use tax on industry output is similar to that of a production tax, as already shown in Figures 8.3a and 8.3b, so we do not replicate that analysis here.[5] Instead, we direct our attention to a general equilibrium analysis of a factor use tax on one factor in one industry on factor use and output in all industries. Figure 8.5 describes the effects of a factor tax – in this case a specific (per worker) tax on labor – on the allocation of the workforce in a two-factor, two-sector model. The economy's two sectors are agriculture and manufacturing, and its two factors are labor and capital. In this beaker diagram, a rightward movement from the left origin on the horizontal axis indicates an increase in the employment of labor in manufacturing, and a leftward movement from the right origin describes an increase in the employment of labor in agriculture. Employment in the two sectors sums to QF, the total labor force.

An assumption of the model is that labor is fully mobile across the two sectors, but that capital is fixed in each industry at its initial quantity. This assumption means that the theoretical model describes adjustment over a shorter time frame than in the CGE models with fully mobile factors that we mostly have used for demonstration. The industry demand curves

[5] Like a production tax, a factor tax increases the cost of production and shifts the supply curve inward. However, a factor use tax can have a smaller impact on production costs than an equivalently sized production tax if producers can substitute away from the taxed factor within the value-added bundle.

for labor by the manufacturing ($D_M{}^1$) and agricultural (D_A) sectors are downward sloping. This reflects the assumption that the marginal revenue product (MRP) of labor (the additional revenue earned from the addition of one more worker) declines in both industries as the quantity of labor increases relative to the fixed quantity of capital. The MRP of each industry describes the wage that a firm is willing to pay. For example, as the ratio of farm workers to a fixed number of tractors increases from zero, moving leftward on the horizontal axis, the marginal revenue product and wage of each additional farm worker in agriculture gradually falls.

In the initial equilibrium, employment is allocated across the two industries at L^1. This allocation of labor equalizes the wage across the two industries at W^1, the economy-wide wage. Suppose the economy were not at equilibrium, and instead had a labor allocation such as L^X. At this point, the MRP of labor in agriculture, which is the vertical height of the intersection of L^X and D_A, exceeds that in manufacturing. Agriculture's higher wage will attract labor into agriculture. The decline in the ratio of workers to capital in manufacturing will cause an increase in labor's MRP in manufacturing sector, in an upward movement along $D_M{}^1$. And the higher labor-capital ratio in agriculture will lower the MRP of farm labor, in a downward movement along D^A, until the MRP of labor in both industries equalize at L^1 and wage W^1.

The introduction of a specific labor use tax in manufacturing shifts manufacturers' after-tax labor demand curve downward, to $D_M{}^2$. As the manufacturing wage falls, for any given quantity of labor, workers move from manufacturing into agricultural employment. At the new equilibrium, the employment allocation is L^2, the economy-wide wage falls to W^2, and manufacturers pay a wage plus tax of W^{2+t}. The wage is now lower in manufacturing because the tax reduces its demand for labor, and it is lower in agriculture because the increase in its labor force causes the MRP of its workers to decline.

The direct burden of the factor use tax is the sum of rectangles $a + c$, which is the amount of tax revenue generated by the employment of L^2 workers in manufacturing. The excess burden of the tax related to manufacturing is the sum of triangles $b + d$. Labor employment in manufacturing is now inefficiently low because the marginal product of each additional worker between L^2 and L^1 exceeds its marginal cost, measured by curve D_A.

We simulate a factor use tax in one sector in a CGE model by conducting an experiment that introduces a 15% ad valorem tax on labor employed in U.S. manufacturing. We use the TAXToy CGE model with the distortion-free U.S. 3×3 database. We assume that the capital stock employed in each industry is fixed but that labor is fully mobile among sectors. Our CGE model differs from our theoretical model because it has a third factor of production – land. Similar to capital, we assume that a fixed quantity of land is employed

Table 8.9. *Effects of a 15% Tax on Labor Used in U.S. Manufacturing*

Effects on Industries (% change from base)	
Employment in manufacturing (*qfe*)	– 5.4
Employment in agriculture (*qfe*)	1.2
Employment in services (*qfe*)	1.1
Economywide wage (*ps*)	– 5.1
Wage (including tax) in manufacturing (*pfe*)	9.2
Agricultural production (*qo*)	0.4
Manufacturing production (*qo*)	– 3.8
Services production (*qo*)	0.8
Government revenue ($U.S. billion) (NETAXES)	196.0
Efficiency loss ($U.S. billion)	– 5.6
U.S. welfare (EV) ($U.S. billion)	– 33.2

Source: TaxToy CGE model with distortion-free U.S. 3×3 v.8.1 database. Capital stock is fixed by sector.

in agriculture. For brevity, we do not include land in our discussion of results.

Consistent with our theoretical model, the labor tax raises employers' cost per worker in manufacturing and reduces their labor demand (Table 8.9). In the new equilibrium, manufacturing employment falls by 5.4%. Higher employment in agricultural and services employment causes declining labor productivity in those two industries, which also contributes to a decline in the economy-wide wage of more than 5%. Yet, manufacturers pay an after-tax

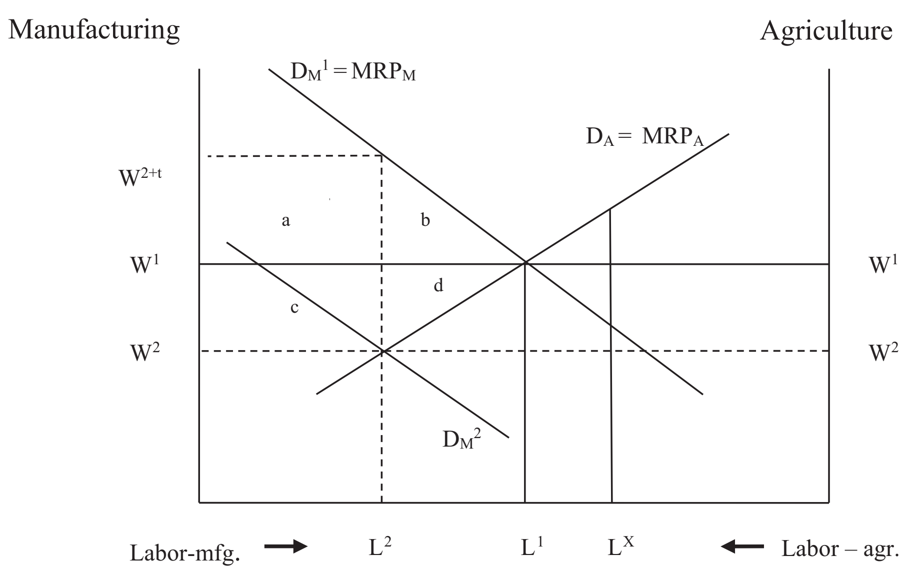


Figure 8.5. Effects of a factor tax on the economy-wide labor market.

wage that is 9.2% higher because of the tax. Increased agricultural and services employment also contribute to a change in the industrial structure of the economy. Agriculture and services output increase while manufacturing output declines.

Our CGE model quantifies the direct and excess burdens illustrated in Figure 8.5. The direct burden of the tax is $196 billion. The excess burden, or efficiency effect, in manufacturing is a loss of $5.6 billion. The national welfare effect includes both the efficiency loss and a deterioration in the U.S. terms of trade, resulting in a total U.S. welfare loss of nearly $33.2 billion.

Income Taxes

Income taxes, also called direct taxes in CGE models, are paid by factors of production or by households, usually as a percentage of their income from land rents, wages, and capital returns. Income taxes differ in an important respect from the indirect taxes discussed previously. Because they are not imposed directly on goods and services, they do not alter relative market prices. They do not make textiles and apparel more or less expensive than food, for example. Because they do not directly influence relative prices, they are generally less distorting of production and consumption decisions, and therefore of economic efficiency, than indirect taxes are.

Income taxes do affect things like after-tax, or net, wage. When income taxes lower net wages, some people may choose to work less and spend more time on leisure activities. A decline in net wages can also motivate some people to work more hours, instead of less, if they need the additional earnings to compensate for the fall in their after-tax income. Income taxes, in addition, may cause households to change their allocation of income between consumption and savings and therefore affect the rate of return on savings. This is an intertemporal distortion because it changes the timing and amount of consumption over a lifetime and the availability of savings for investments in future production. Income taxes also can influence households' investment allocations if tax rates differ among asset classes as they do in the case of wage income and capital gains. For these reasons, income taxes are likely to distort some household decisions.

These impacts of income taxes on labor supply, and on savings and investment decisions, though very important, are not accounted for in the standard CGE model that we are studying. Dynamic, multiperiod CGE models are needed to analyze the intertemporal effects of income taxes, and a labor-supply response must be incorporated to analyze the tax's effects on individuals' labor-leisure trade-off. A prominent example of a CGE model with both of these features was developed by Auerbach and Kotlikoff (1987) and used to analyze U.S. tax policies. A subsequent version of this model, developed

Text Box 8.2. U.S. Tax Reform in a Dynamic Overlapping-Generations CGE Model

"Simulating the Dynamic Macroeconomic and Microeconomic Effects of the FAIR Tax" (Jokisch and Kotlikoff, 2005).

What is the research question? The Fair Tax is a proposal to replace the U.S. federal payroll tax, personal income tax, corporate income tax, and estate tax with a progressive federal retail sales tax on consumption. Given the aging of America's population, which will lead to growing health and pension costs, could adoption of the FAIR Tax Act preclude the need for higher taxes to fund these liabilities, and even lead to welfare gains?

What is the model innovation? The authors' dynamic, overlapping generations, CGE model captures detailed demographic characteristics of the U.S. economy, including age- and year-specific projections for three income classes of households within each generation (e.g., mortality rates, pension benefits, health costs). The model also includes year-specific projections of government revenue and expenditure.

What is the experiment? The authors model the Fair Tax as the replacement of most federal taxes by a progressive federal retail sales tax of 23% on consumption (i.e., it increases a sales price of $1 to $1.23). The plan includes a tax rebate whose size depends on households' characteristics and an increase in Social Security benefits to maintain their real purchasing power. Their tax plan reduces non–Social Security federal expenditures to help pay for the Fair Tax rebate.

What are the key findings? The Fair Tax almost doubles the U.S. capital stock by the end of the century and raises long-run real wages by 19% compared to the base case alternative. The winners from this reform are primarily those who are least well off, and large welfare gains accrue to future generations.

by Jokisch and Kotlikoff (2005) and summarized in Text Box 8.2, was used to analyze the FAIR Act. (The FAIR Act is a plan to replace most types of U.S. taxes with a single sales tax on consumers.) Equity considerations of income taxes and income subsidies are other dimensions not typically addressed in a standard CGE model. Nevertheless, standard CGE models must still account for income taxes, even if in a rather simplified way, because they are a part of the circular flow of national income and spending.

However, even among standard, static CGE models, the presentation of income tax data in a SAM, and its treatment in the corresponding CGE model, may differ in meaningful ways. For this tax in particular, it is important to study your SAM in order to understand how the tax is assumed to affect behavior in the model. Let's first consider how income tax is described in the U.S. 3×3 SAM, which includes a regional household. In the U.S. SAM, income taxes are paid directly from the column accounts of the factors of

Table 8.10. *Income Tax Data in a U.S. SAM with a Regional Household ($U.S. billion)*

	Land	Labor	Capital	Income tax
Income tax	3	1,742	294	–
Regional household	33	6,463	1,994	2,039
Total factor income	36	8,205	3,548	–
Income tax rate	8.3	21.2	8.3	–

Source: GTAP v8.1 U.S. 3×3 database. Capital income includes depreciation expenses of $1,260 billion.

production to the income tax row account (Table 8.10). Factors pay their remaining, after-tax income directly to the regional household row account. Then, the income tax column account pays all of its tax revenue to the regional household row account. Therefore, all income in the economy – which is the sum of income taxes plus after-tax income – is ultimately paid to the regional household.

The income tax rate for each factor is calculated as:

$$\text{Income tax/total factor income} * 100$$

As an example, the income tax rate for labor is:

$$1{,}742/8{,}205 * 100 = 21.2\%$$

In the U.S. SAM, the tax rate on wage income is quite high relative to the tax rates on land-based income and capital income – which are both 8.3%.

Recall from Chapter 3 that the regional household is a macroeconomic account in the GTAP model and SAM that is similar to GDP. (It excludes spending needed to replace depreciated, worn-out capital, and thus measures net domestic product [NDP].) This account describes the sources of national income and the composition of aggregate demand. In a CGE model with this structure, a change in the income tax typically has no effect on the economy. To explain why, consider the income tax on labor in Table 8.10. Labor ultimately pays a total of $8.2 trillion to the regional household, composed of income taxes of $1.7 trillion plus after-tax income of $6.5 trillion. If the labor income tax rate should fall to zero, labor would still pay $8.2 trillion to the regional household, now composed entirely of after-tax income. Thus, a change in the income tax does not change regional household income or the shares of households, government, and savings in national spending.

In some static CGE models without a regional household, an income tax has structural effects on an economy if it shifts spending power among the categories of final demand. CGE models without a regional household generally link income directly to each component of aggregate demand.

For example, households spend their after-tax income and governments spend their tax revenue, so an increase in an income tax lowers household spending and increases government spending. Depending on the closure in these models, income taxes also may affect investment by changing households' after-tax savings or the government surplus or deficit (which is public savings). If households, governments, and investors differ in the type of goods that they demand, then a change in income taxes and the composition of final demand will lead to changes in the industrial structure of the economy.

Second-Best Efficiency Effects

So far, we have used a distortion-free model of the United States to study the direct and excess burdens of one type of tax at a time. In more realistic CGE models, and in real life, governments usually impose many taxes at the same time, and usually in many industries simultaneously. Policy changes therefore entail introducing or changing a tax in the presence of many preexisting tax distortions.

This tax setting raises an important question: Does the excess burden of a tax depend on the preexisting taxes in an economy? To answer this, we draw on the theory of the second best developed by the economists Richard Lipsey and Kelvin Lancaster (1956). According to this theory, a free-market equilibrium in one market may not lead to the most efficient, economy-wide outcome if there is already a distortion in another market due to a tax, a market failure, or other type of economic constraint. For example, suppose there is already a production subsidy in the services industry that has caused its output to exceed the economically efficient level. The government now may be considering the introduction of a production subsidy to the manufacturing industry. In this distorted setting, the manufacturing subsidy could actually improve economic efficiency in the services sector by drawing away some of its productive resources. In this case, a new, distorting manufacturing subsidy would be preferable to no manufacturing subsidy if it cancels out at least part of another subsidy's distortionary effect. Of course, there are circumstances where a new tax or subsidy can exacerbate the effects of existing tax distortions.

Let's explore a case of second-best in our GTAP model with the distortion-free U.S. 3×3 database. First, we assume that there are no other tax or subsidy distortions in the economy. Our experiment is the introduction of a 10% ad valorem production subsidy on U.S. manufacturing. The subsidy causes manufacturing output to increase by 8.65%, an oversupply relative to the free-market level (Table 8.11). The excess burden in manufacturing of $23.9 billion corresponds to the efficiency triangles of c + *f* in Figure 8.3b. The

Table 8.11. *Second-Best Effects of a Production Subsidy in U.S. Manufacturing with/without a Preexisting Production Subsidy in U.S. Services*

	Base Production Subsidy	New Production Subsidy	% Change in Production (*qo*)	Excess Burden ($US million)
Base equilibrium with no preexisting tax distortions				
Agriculture	0	0	−2.30	0
Manufacturing	0	10	8.65	23,919
Services	0	0	−1.87	0
Base equilibrium with a preexisting subsidy				
Agriculture	0	0	−2.28	0
Manufacturing	0	10	8.85	23,790
Services	5	5	−1.86	−14,047

Source: TaxToy CGE model with distortion-free U.S. 3×3 v.8.1 database.

increased use of the economy's resources by manufacturing also causes the production of agriculture and services to decline.

Now, we assume that the economy has a preexisting, 5% subsidy on the production of services. In this setting, there is already an oversupply of services relative to the free-market level. The introduction of the manufacturing production subsidy increases manufacturing output (8.85%) and leads to an efficiency loss in the industry of $23.8 billion. However, in this case, manufacturing's expansion corrects for part of the inefficient oversupply of services. Its competition for the economy's productive resources causes services output to decline and yields a reduction of $14 billion in the excess burden associated with service's production subsidy. The new distortion in the manufacturing sector therefore corrects for part of a preexisting distortion in the services sector.

Our simple example analyzes just two taxes. A CGE model with a more realistic SAM is likely to have a large number of taxes. The efficiency effect of a change in any one tax is therefore the sum of its own excess burden plus its second-best effects in correcting or exacerbating the excess burdens associated with every other tax in the model.

Marginal Welfare Burden of a Tax

The marginal welfare burden of a tax is the change in national welfare due to a very small – marginal – change in an existing tax. The change in welfare, divided by the change in tax revenue, describes the marginal welfare burden per dollar of additional tax revenue. This per-dollar concept, developed by Edgar Browning (1976), has had practical use as a yardstick for determining whether a government project is worthwhile if its funding requires raising additional tax revenue. This is a realistic and important analytical problem because policymakers are typically seeking ideas for designing modest tax hikes or tax cuts from an already distorted tax base.

The yardstick builds on the idea that every additional dollar of tax revenue incurs both a direct tax burden, which is a transfer of tax revenue from private expenditure to the government, and an excess tax burden, which is the tax's deadweight efficiency cost to the economy. Browning studied the marginal excess burden of the U.S. labor income tax, finding that raising an additional dollar of tax revenue would generate an excess burden of 9–16 cents, depending on how the tax increase is structured. He concluded that the return on a government project funded by this additional tax revenue would have to be 9–16% greater than the private expenditure that it displaced, or national welfare would decline.

Browning used a partial equilibrium model for his study of the labor income tax, but CGE models have proven to be well suited for this type of analysis. One reason is that CGE models offer a comprehensive measure of the welfare effects of a change in one tax. The model takes into account not only the excess burden of the tax that changes but also any second-best efficiency effects linked to other existing taxes. In addition, a CGE model's welfare measure includes any terms-of-trade effects due to the tax change, which may be important when the country is large in world markets.

CGE models also provide a comprehensive measure of the direct burden of a tax because they account for the impacts of a change in one tax on the revenue generated by all taxes in an economy. For example, an increase in the sales tax on cigarettes may cause employment and output in the tobacco industry to fall. Payroll and production taxes paid by the tobacco industry may then fall, and perhaps sales tax revenue from other goods will rise as consumers readjust their spending. Thus, the total change in tax revenue will likely include changes in revenue from many types of taxes in addition to the tobacco sales tax.

Ballard, Shoven, and Whalley (1985) developed a pioneering CGE-based analysis of the marginal welfare cost of the entire U.S. tax system. They found that, depending on the elasticities assumed in the model, the marginal welfare cost per dollar of additional U.S. labor income tax revenue was between 12 cents and 23 cents – substantially higher than Browning's partial equilibrium estimate. For the U.S. tax system as a whole, they calculated a marginal welfare burden of 17–56 cents per dollar of additional tax revenue. For example, a ratio of 17% indicates that for a dollar of additional tax revenue there is an additional deadweight efficiency loss to the economy of 17 cents. In this case, a government project must yield a marginal return of at least 117% if it is to be worth its cost to the economy in terms of tax dollars spent plus lost efficiency. (You will replicate the Ballard,

Text Box 8.3. Marginal Welfare Burden of Taxes in Developing Countries

"The Marginal Cost of Public Funds in Developing Countries" (Devarajan, Thierfelder, and Suthiwart-Narueput, 2001).

What is the research question? The notion that raising a dollar of taxes could cost society more than a dollar is one of the most powerful ideas in economics. By causing agents to alter their behavior in inefficient ways as a result of the tax, the marginal cost of raising a dollar of public funds is higher than a dollar. Despite the importance of this idea, few estimates are available on the marginal welfare cost of funds in developing countries. What are the estimated costs of public funds in three developing countries – Cameroon, Bangladesh, and Indonesia?

What is the CGE model innovation? A standard, static, single-country CGE model is used for each country. Their macroclosure rules fix investment, real government spending, and the current account balance. These closure rules imply that an increase in tax revenue causes a government budget surplus (i.e., public savings rise), but because investment spending is fixed, households' savings falls and their consumption rises by the full amount of the tax revenue. In effect, households are compensated in a lump-sum fashion for higher taxes so that model results measure only the excess burden of the taxes.

What is the experiment? There are four tax experiments for each country: (1) an increase in the production tax by sector; (2) a uniform increase in all production taxes; (3) an increase in individual tariff rates; and (4) a uniform tariff rate increase. Additional factor market distortions are introduced one-by-one into the Cameroon model to illustrate second-best effects.

What are the key findings? The marginal costs of funds in the three countries are quite low, ranging between 0.5 and 2.0, which refutes the conventional wisdom that the marginal costs of funds in developing countries are likely to be high because of their relatively high tax rates. Experiments in which taxes are increased by sector confirm that the marginal cost of funds is highest in sectors where distortions are large. Policies that increase the lowest tax rates tend to reduce the marginal cost of funds because the tax structure becomes more uniform.

Shoven, and Whalley analysis in Model Exercise 8.) Devarajan, Thierfelder, and Suthiwart-Narueput (2001) carried out a similar CGE-based analysis of the marginal costs of taxes in three developing countries, described in Text Box 8.3. Their study is of special interest because most studies of marginal welfare burdens focus on developed countries.

The concept of the marginal welfare burden is illustrated in the partial-equilibrium model shown in Figure 8.6. The figure describes changes in direct and excess burdens due to marginal increases in a production tax. In the figure, S^1 is the tax-free supply curve and, to simplify our analysis, D describes a perfectly elastic compensated demand curve. In the absence of the tax,

QO^1 is the initial equilibrium output quantity. PS^1 is the equilibrium supply price and, in the absence of a sales tax, it equals PD, the initial consumer price for the domestically produced product. Now, assume that a specific (per unit) production tax of t^1, shown as the distance between $PS^1 - PS^2$, is already present in our initial equilibrium. The tax-inclusive supply curve corresponding to t^1 is S^2. In this tax-distorted equilibrium, consumers pay price PD for quantity QO^2 and producers receive price PS^2. The total loss in producer surplus is the combined area of $a + b + c + d$, but of this total, area $a + b + c$ is transferred to the government as tax revenue, so it is not a loss to the economy. The excess burden of the tax is the area of triangle d.

Next, assume a marginal increase in the production tax to t^2, shown in the figure by the distance PS^2-PS^3. The increased tax raises producers' costs of production and shifts the new tax-inclusive supply curve to S^3. In the new equilibrium, consumers still pay price PD, but producers receive only price PS^3 and the equilibrium quantity declines to QO^3. Producers lose the additional producer surplus areas of $e + f$. (The small triangular area to their right can be ignored for small changes in the tax.) The government gains new tax revenue of area $e + f$ but loses tax revenue of area c. Area c becomes an addition to area d, the excess burden of the tax, as the tax increases from t^1 to t^2.

The marginal excess burden of the tax per dollar of additional government revenue is the ratio of the change in the excess burden to the change in tax revenue. In Figure 8.6, the ratio is described as areas $c/(e + f - c)$ for the tax increase from t^1 to t^2.

Our partial equilibrium model shown in Figure 8.6 describes only the change in excess burden in the taxed sector. Recall from our study of the

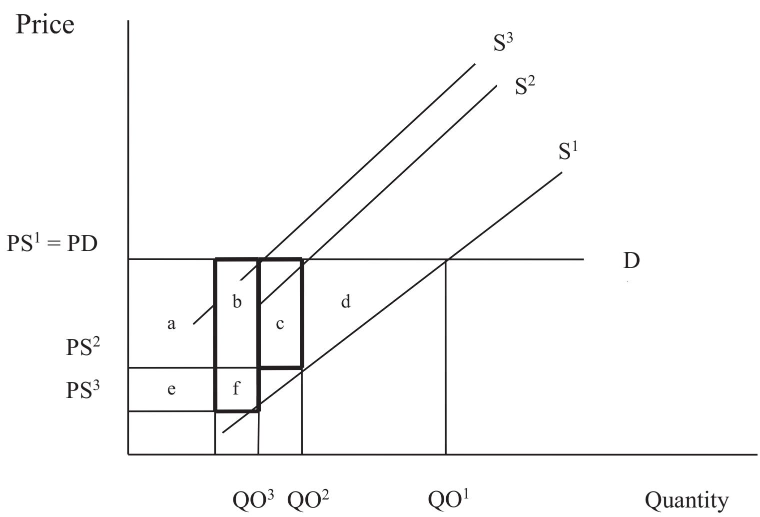


Figure 8.6. Marginal excess burden of a production tax.

Table 8.12. *Marginal Welfare Effect of a 1% Increase in the U.S. Consumer Sales Tax on Domestically Produced Manufactures ($U.S. million)*

Excess Burden by Tax	
Total excess burden	– 87.6
Import tax	5.2
Export tax	1.3
Production tax	7.8
Sales tax on intermediate inputs	– 0.4
Sales tax on final demand	– 101.9
Factor use tax	0.3
Terms of trade	– 148.7
Total welfare effect	– 236.3

Source: GTAP CGE model, U.S. 3×3 v.8.1 database.

theory of the second best that, in an economy-wide framework, a change in one tax rate may cause the excess burdens associated with other taxes in the economy to change also. In a general equilibrium model, therefore, measurement of the marginal welfare effect will include the marginal excess burden associated with all taxes in the economy, as well as any changes in the terms of trade. Changes in tax revenue, too, are the sum of changes in revenue from all tax sources.

To illustrate these points, we use the GTAP model with our regular (tax-distorted) U.S. 3×3 database to analyze the welfare effect of a marginal, 1% increase in the initial 10.1% tax on U.S private consumption of domestically-produced manufactures. Our model results indicate that the increase in the sales tax increases the total excess burden, or efficiency loss, by $87.6 million and causes welfare to decline by $236.3 million (Table 8.12). The efficiency losses are associated with the consumer sales tax and intermediate input sales tax, whereas other types of taxes generate second-best efficiency gains. Total U.S. tax revenue increases by $1,029 million. Thus, the marginal welfare burden of the additional tax revenue is:

$$\text{Change in welfare/Change in tax revenue} * 100$$

$$-236.3/1{,}029 * 100 = -22.3\%.$$

This means that an additional dollar in revenue from the consumer tax on manufactures costs 22.3 cents in efficiency losses. The government project should be undertaken only if its marginal benefit will be at least 22.3% greater than the amount of the additional consumer tax revenue required to finance it. Otherwise, its cost to the economy in terms of tax dollars spent plus related efficiency losses will be greater than its benefit.

In an already distorted economy, it is also possible that the tax increase could lead to marginal welfare gains. In this case, the ratio is positive. If, for example, the ratio is 10%, then a public project could generate a marginal benefit that is as little as 90% of its cost in taxpayer funding and still be worthwhile because the tax increase corrects other distortions in the economy. This scenario may not be too far-fetched; our model results in Table 8.12 showed that a marginal increase in a U.S. consumer sales tax yielded second-best welfare gains associated with some preexisting U.S. taxes.

Preferential Tariffs

Preferential trade agreements (PTAs) are pacts among like-minded trade partners to reduce or eliminate trade barriers among themselves while retaining barriers against nonmembers of the agreement. Because *multilateralism*, in which all countries agree to liberalize trade barriers, is a first-best, welfare-enhancing strategy, might the reduction of barriers among a subset of countries in a PTA also be welfare increasing? In this section, we study the welfare effects of a preferential elimination of import tariffs, a second-best tax problem. Efforts in some recent PTAs to harmonize regulations that impede trade and investment flows have added additional dimensions to the analysis of these agreements. We address the welfare impacts of regulations in detail in Chapter 9.

The seminal theory of customs unions was developed by Jacob Viner (1950) and still serves as the foundation for economic analyses of trade preferences. He introduced the concepts of *trade creation* and *trade diversion*, which contrast the welfare-improving impacts of trade reforms within the pact with the welfare-reducing impacts of the accompanying trade discrimination. Viner defined trade creation as the shift in the volume of production of a traded good from a high-cost producer in the pact to a lower-cost member. The resulting increase in production efficiency unambiguously increases global welfare. Trade diversion occurs when a member shifts its source of imports from lower-cost nonmembers to higher-cost PTA partners. This reduces production efficiency and welfare.

Subsequent refinements of Viner's ideas added an important insight.[6] Viner focused only on shifts in traded quantity toward more or less efficient producers. He overlooked the gain in consumption efficiency that occurs when consumers can purchase a larger quantity of the good than originally because of its lower, duty-free domestic price. The consumption efficiency gain from this trade expansion augments the production efficiency gains

[6] Johnson (1962) and Kendall and Gaisford (2007) offer clear expositions of customs union theory. Baldwin and Venables (1995) and Panagariya (2000) survey its more recent extensions.

from Viner's trade creation. And if trade expands when a member shifts its sourcing from lower-cost nonmembers to its preferred partner, then even a trade-diverting PTA can be net trade-creating if the increase in consumption efficiency is greater than the loss in production efficiency. Members are likely to experience trade creation for some products and trade diversion for others. Whether the PTA is trade creating or diverting therefore must be analyzed on a case-by-case, empirical basis.

When countries are large in their import markets, a change in their quantity of demand for imports also can lead to terms-of-trade changes. In general, an increase in a member's demand for imports from its PTA partner will cause its import price to rise and its terms of trade to deteriorate. This may be offset by terms-of-trade gains if its partner likewise increases the quantity of imports that it demands from the member. A member may garner terms-of-trade gains, too, if the fall in the quantity of imports that it demands from nonmembers causes their export prices to fall.

Customs union theory describes the welfare effect of a PTA on each member as the sum of the efficiency gains or losses that result from trade creation and diversion and its terms-of-trade change. A PTA affects nonmembers, too, through changes in their terms of trade and efficiency. Because one country's terms-of-trade gain is its trade partner's loss, terms-of-trade effects cancel out at the global level. Global welfare is therefore the sum of regions' gains and losses in efficiency.

We examine the impact of a PTA on a member country using the partial equilibrium frameworks shown in Figures 8.7 and 8.8. Let's assume that

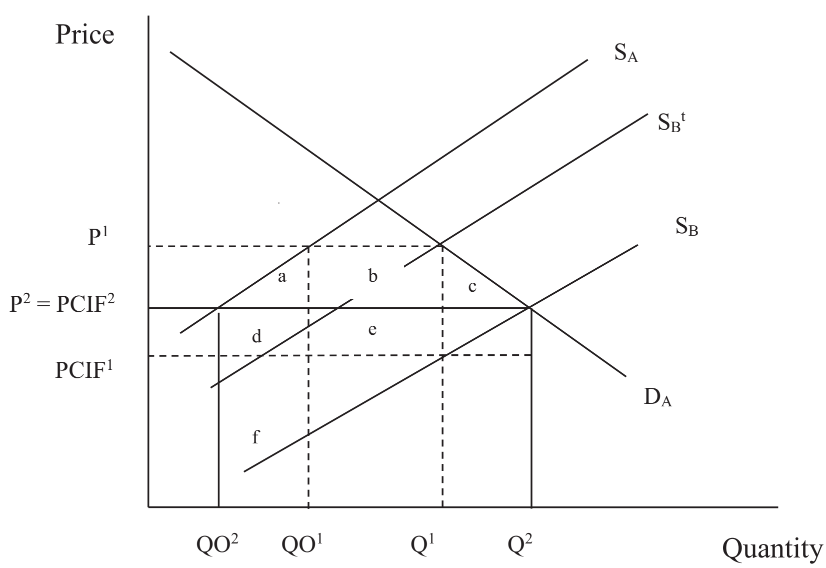


Figure 8.7. Trade creation in a preferential trade agreement.

countries A and B join a PTA, in which they eliminate bilateral tariffs, and that country C represents nonmember countries. Figure 8.7 describes the trade-creating effects of the PTA on A's welfare. In the figure, D_A is the demand in country A for a composite product that is satisfied through a combination of the domestically produced and imported varieties. S_A is the supply curve for production in A, S_B is the supply curve for the import from B, and $S_B{}^t$ is the import supply curve from B inclusive of A's initial, per-unit import tariff. The vertical distance between S_B and SB^t measures A's per-unit tariff on a given quantity of imports from B. A's initial consumption is quantity Q^1 at the domestic consumer price of P^1 and a pre-tariff, *cif* import price from B of $PCIF^1$. Quantity QO^1 is supplied by domestic production and quantity $QO^1 - Q^1$ is imported from B. Country A imports solely from B because C is the highest-cost producer (its supply curve is not shown).

After A eliminates it tariff on B, A's new equilibrium is at the intersection of A's demand curve and B's duty-free import supply curve S_B. As the domestic price of imports from B falls, A's imports from B increase to $QO^2 - Q^2$. The trade creation effect of the PTA includes the decline in A's production from $QO^1 - QO^2$, as domestic output is replaced by imports, and the expansion of A's consumption from Q^1 to Q^2. The price of A's composite consumption good falls to P^2 and the price of its imports from B rises to $PCIF^2$.

Country A's efficiency gains are described by triangles *a* and *c*. Triangle *a* measures the welfare effects of Viner's trade creation. It is a production efficiency gain because the supply of QO^1 to QO^2 had cost areas $a + d + f$ when produced domestically but now costs only areas $d + f$ when replaced by imports from B. Triangle *c* measures the gain in consumption efficiency resulting from the expansion of trade from Q^1 to Q^2. Area $b + e$ is the loss in tariff revenue, but this does not affect welfare because it is redistributed back to A's consumers. Area *e* measures the terms-of-trade loss to A because it must now pay a higher price for its initial quantity of imports. On net, the welfare effect of the PTA on A depends on whether its efficiency gains from trade creation (area *a* and *c)* are greater than its terms-of-trade loss to B (area *e*).

The trade-diverting impacts of a PTA on a member are described in Figure 8.8. The graph describes A's imports from B and C, with the Armington assumption of zero production of the imported varieties by A. We can think of the products of B and C as being strong substitutes of the same good, although they are differentiated varieties due to our Armington assumption. In the figure, D_A is the demand for the composite import in country A. S_B is the supply curve for imports from B. Country C is the low-cost supplier with an import supply curve S_C and a tariff-inclusive import supply curve $S_C{}^t$. The vertical distance between S_C and $S_C{}^t$ measures A's per-unit tariff on a given

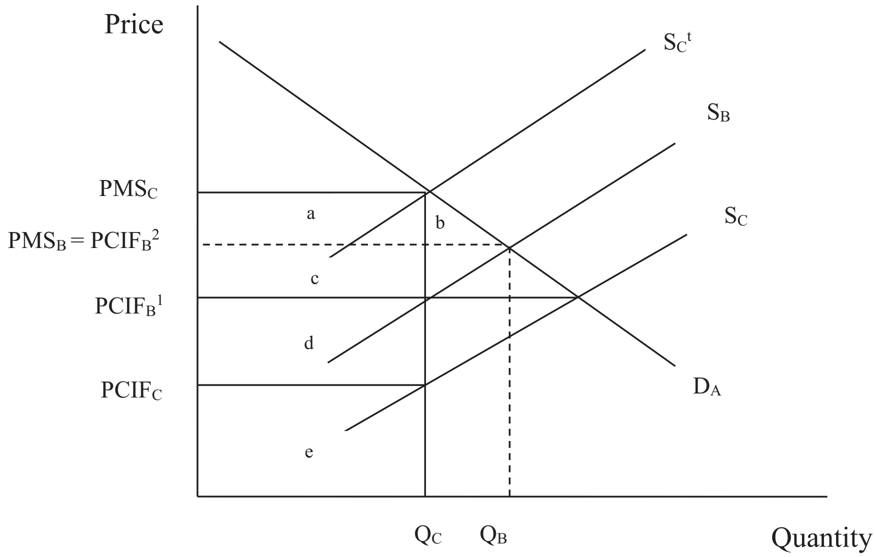


Figure 8.8. Trade diversion in a preferential trade agreement.

import quantity. In the initial equilibrium, A imports only from C, purchasing Q_C at an import price from C of $PCIF_C$ and A's tariff-ridden, bilateral domestic import price of PMS_C. Area $a + c + d$ measures A's initial tariff revenue. Country A has zero initial imports from B because it is a high-cost supplier (its tariff-ridden supply curve is not shown).

With the formation of a PTA between A and B, B's duty-free price ($PCIF_B^1$) is lower than C's tariff-ridden price. In the new equilibrium, A's imports are now sourced only from B at quantity Q_B. A's domestic import price from B is PMS_B; in the absence of a tariff it is equal to $PCIF_B^2$. Tariff revenue declines by area $a + c + d$ but this has no welfare impact because it is redistributed back to consumers. Area c is A's terms-of-trade loss because B's price for the initial import quantity has increased to from $PCIF_B^1$ to $PCIF_B^2$. Area d is an efficiency loss to A due to B's higher costs of production relative to C on the diverted volume of trade. The gain in A's consumer surplus due to the expansion of consumption from Q_C to Q_B is described by area *b*. The net welfare effect of the PTA on A depends on whether its gain in consumption efficiency due to trade expansion is greater than the sum of its production efficiency loss from the diversion of its initial quantity of trade and its terms-of-trade deterioration on imports from B.

We explore these ideas in a general equilibrium framework using, for demonstration, PTAToy, which is the GTAP CGE model and the PTA3×3 database. The database is a three-sector, three-factor aggregation with three regions: the United States, the European Union (EU), and an aggregated

Table 8.13. *Trade Creation and Diversion Effects of a U.S.-EU Preferential Trade Agreement (2007 $U.S. millions)*

	EU real imports from		U.S. real imports from	
	United States	Rest of World	EU	Rest of world
Agriculture	952	–175	228	68
Manufacturing	32,313	–4,417	29,630	–5,887
Services	–1,214	1,365	529	1,268

Source: PTAToy CGE model and PTA3×3 v8.1 database.

rest-of-world. Our experiment describes a U.S.-EU free-trade area in which bilateral import tariffs are eliminated but the two members maintain their barriers against the rest of the world.

Table 8.13 reports the real import (quantity) changes depicted as trade creation and trade diversion in Figures 8.7 and 8.8.[7] Notice that whereas our simple theoretical model describes the elimination of members' trade with nonmembers, our CGE model finds that both the United States and the EU continue to import goods from the rest of the world. Specialization is unlikely to occur in a CGE model because of the Armington assumption that the varieties imported by A from B and C are imperfect substitutes.

The agreement is net trade creating for the EU in all industries because the increase in the quantities of its imports from the United States exceeds the diversion of its imports of those goods from the rest of the world. For example, the increase in the quantity of EU agricultural imports from the United States, worth $952 million dollars, diverts only $175 million dollars' worth of agricultural goods imports from the rest of the world. The agreement is also net trade creating for the United States in all products.

We use the GTAP model's welfare decomposition utility to quantify the equivalent variation welfare impacts of the PTA that are associated with the changes in trade quantities. The first column in Table 8.14 describes the allocative efficiency gains for the EU and the United States that result from their removal of bilateral import tariffs. These gains measure the welfare

[7] Why are changes in traded quantities expressed in value terms? We can calculate the change in the "real" value of trade by comparing pre- and post-shock quantities that are both valued at the same initial prices. Because the new value of imports is not affected by changes in price, the calculated change in import value measures only quantity changes. In the GTAP model, we multiply coefficient VXMD by variable *qxs*, where VXMD is the initial quantity of bilateral exports valued in the normalized producer price in the source country and *qxs* is the percent change in bilateral export quantities. The change in value is expressed in $US2007 dollars, which is the base year for the GTAP v8.1 database. Hertel et al. (2004a) provide a detailed discussion of this measure of trade creation and diversion in the context of the GTAP welfare decomposition utility.

Table 8.14. *Decomposition of the Equivalent Variation Welfare Effects of a U.S.-EU Preferential Trade Agreement ($U.S. millions)*

	Allocative efficiency effects from bilateral tariff reform	Other allocative efficiency effects	Terms of trade	Investment-savings	Total welfare gain
European Union	362	247	234	−475	369
United States	199	277	3,932	1,503	5,911
Rest of world	–	−905	−4,172	−1,030	−6,107
World total	561	−381	–	–	172

Source: PTAToy CGE model and PTA3×3 v8.1 database.

triangles *a* and *c* in figure 8.7, for each country, and yield the two members a combined gain of $561 million.

Our general equilibrium model also accounts for the second-best interactions of the U.S. and EU bilateral trade reforms with the remaining tax and subsidy distortions in their economies. These result in second-best efficiency gains of $247 million in the EU and of $277 million in the United States. The PTA's terms-of-trade effects redistribute import-purchasing power among the regions. These effects include changes in both the export prices and import prices for each region. Gains in the terms of trade are mostly garnered by the United States, with small positive gains in the EU's terms of trade; both members gain at the expense of the rest of the world. The investment-savings terms of trade, which describes changes in the purchasing power of a country's savings for capital investment goods, reveals mixed impacts on the PTA members.

Our multi-country CGE model also provides us with a detailed view of the effects of the PTA on nonmembers. In addition to its terms-of-trade losses to the PTA members, the aggregated rest-of-world region experiences an allocative efficiency loss of almost $1 billion related to the taxes and subsidies in its economy.

In our CGE model, the changes in bilateral trade flows are driven not only by the new trade preferences but also by the general equilibrium outcomes of the PTA. The shift in the EU's sourcing of its services imports away from the United States and toward the rest of the world, despite the PTA, provides a good example. Because there are no preexisting tariffs on trade in services in any of the three regions, this trade result is driven only by the general equilibrium impacts of the PTA, with no role for tariff preferences. The PTA causes the EU's real exchange rate to depreciate relative to the United States but to appreciate relative to the rest of the world. This appreciation makes the rest of the world the lower-cost supplier, compared to the

United States, of the EU's services imports, so EU services imports from the United States fall despite the PTA. Similarly, the United States increases its services imports from both the EU and the rest of the world because of its real exchange rate appreciation relative to both regions. The general equilibrium effects of the PTA make it pure trade creating in services, in the sense that neither member reduces its services imports from the rest of the world.

Our analysis finds that the EU-U.S. free-trade agreement is welfare improving for its members, but welfare declines substantially in the rest of the world. Because terms-of-trade changes cancel each other out at the global level, only changes in allocative efficiency are included in a measure of a PTA's global welfare impact. With a total global efficiency gain of approximately \$172 million, the PTA is globally welfare improving.

Summary

Our study of tax policy analysis in a CGE model began with an examination of the tax data in the SAM, because the SAM describes the agent who pays the tax, the production or consumption decision on which the tax is assumed to be levied, and tax revenues. We studied five types of taxes: trade taxes on exports and imports, and taxes on production, sales, factor use, and incomes. Our study of each tax began with a simple, partial equilibrium, theoretical model that illustrated how taxes distort production and consumption decisions and result in a direct burden (the tax revenue that it generates) and an excess burden (the loss in production and consumption inefficiency). Our theoretical approaches helped us formulate expectations about the effects of taxes on the economy under study, identify key results, and recognize the consistency of CGE model results with theoretical models of taxation. We then progressed from analyzing single taxes in partial equilibrium frameworks to analyzing taxes in general equilibrium and presented applied examples of second-best effects, the marginal burden of a tax system, and a preferential trade agreement.

Key Terms

Ad valorem tariff or tax
Deadweight loss
Direct burden
Direct tax
Excess burden
Export tax
Factor use tax

Import tariff
Income tax
Indirect tax
Marginal welfare burden
Multilateralism
Preferential trade agreement
Production tax
Sales tax
Second-best efficiency effects
Specific tariff or tax
Tax incidence
Trade creation
Trade diversion

PRACTICE AND REVIEW

1. Suppose the government is considering the introduction of an import tariff on one of two products; one product exhibits a high own-price elasticity of demand and the other has a low elasticity. In a graph, compare the effects of a tariff on the excess burden for the two goods. Label the axes, curves, and initial market equilibrium. On which type of good do you recommend that the tariff be imposed? Explain why.
2. Use data from the U.S. 3×3 SAM to calculate the factor use tax (or subsidy) rate for labor and capital used in the production of manufactures and of services. Do these factor use taxes distort the allocation of capital and labor between the manufacturing and service sectors? How do they distort the ratios of labor to capital within each industry?
3. Assume that a country introduces a 25% sales tax on the purchase of gasoline. Draw a graph of the effects of the sales tax on the supply and demand for gas. Label the axes and curves and explain your assumptions about the elasticities of supply and demand that define the slopes of your curves. Identify the direct tax burden, the excess burden, and changes in the market equilibrium price and quantity.
4. Suppose that the government increases retail sales taxes on students' purchases of selected items in the university bookstore. Government analysts project a $1 million increase in sales tax revenue that will fund a reduction in student tuition, and a marginal welfare loss of $200,000.
   a. What is the marginal welfare cost of the tax increase, per dollar of additional tax revenue?
   b. What is the minimum return that the government must make on its investment in the university to ensure that national welfare does not decline?
   c. How do you think the marginal welfare cost per dollar might change if the government increases the sales tax on a good for which student demand is relatively price inelastic, such as food?

d. Assume a preexisting production subsidy in the industry that supplies the university bookstore with taxed items, such as textbooks. In a short paragraph, explain the possible second-best effect of the new tax.

5. Assume that Japan and China enter into a free-trade agreement. In a graph, describe its trade-creating and trade-diverting impacts. Select and match the results variables in your CGE model with the key variables in your theoretical, graphical analysis.

9

Regulations in a CGE Model

This chapter examines the treatment of regulations in a computable general equilibrium (CGE) model. Regulations are "command and control" policies that mandate changes in producer or consumer behavior. We study two types of regulations: non-tariff measures that can create barriers to international trade and regulations designed to reduce negative externalities in production. We demonstrate the mechanisms used to introduce a technical non-tariff measure into a CGE model. We describe process-based and outcome-based regulations of externalities and explain their direct and indirect economic impacts. Simple partial equilibrium diagrams illustrate the theoretical effects of the regulations on economic activity and economic efficiency. The results of highly stylized regulatory policy experiments using a CGE model support the theoretical predictions and illustrate modeling methodologies.

Types of Regulations

A vehicle tailpipe emissions standard was first enacted in the United States in 1970 and it has become more stringent over time. The intent of the regulation is to reduce harmful auto emissions, which contribute to today's higher incidence of asthma and other pulmonary health problems, and may be a factor in long-term global warming. According to an analysis of the newest emission standard, a reduction in emissions generates broad gains in the U.S. economy as a whole, not only by reducing health costs and improving the environment but also by increasing employment in industries that supply auto producers with low-emission inputs (U.S. EPA, 2012). Because regulations imposed on a single industry can have important economy-wide impacts, and may have spillover effects on other countries as well, CGE models have become a standard tool for their analysis.

Regulations are command-and-control policies. Unlike taxes, which create price incentives that influence economic choices, regulations are used by the government to directly mandate certain behavior. The mandates are usually negatively enforced with fines, imprisonment, or other undesirable outcomes. Regulations, like taxes, therefore have an impact on resource allocations by producers and consumers. But because regulations do not operate through price mechanisms, as taxes do, they are more challenging to represent in a CGE model, which is fundamentally based on observable market prices and quantities.

"Regulations" is a broad term. There are many types of regulations, which can have a variety of objectives, and may be applied to producers or consumers. A full discussion of regulations and regulatory policy analysis is well beyond the scope of this chapter. Instead, we take a practical approach that focuses rather narrowly on two types of regulations that receive much of the attention in the current CGE-based literature: non-tariff measures (NTMs) that can introduce barriers to international trade, such as border inspection requirements for imported products; and regulations intended to correct negative externalities in production, such as emission limits. These two types of regulations are first introduced in partial equilibrium theoretical models, similar to our treatment of taxes in Chapter 8. We then empirically examine the effects of the regulations using the GTAP CGE model with the US3×3 database. These applications, while highly stylized, demonstrate current methodologies and illustrate both the capabilities and limitations of regulatory policy analysis in a standard CGE model. Many of these limitations have spurred innovations in CGE modeling that substantially extend models' capabilities in regulatory policy analysis.

Because regulations do not affect government revenue or expenditure, as taxes do, we cannot observe them directly in the transactions described in the SAM. They are only indirectly observable in that the flows of income and expenditure in the SAM reflect the impacts of regulations on resource allocations and prices.

Non-Tariff Measures in International Trade

Types of Non-Tariff Measures

A non-tariff measure is defined by UNCTAD (2015) as a policy measure other than an import tariff that can potentially have an economic effect on international trade in goods by changing the quantities traded, their prices, or both. Because import tariffs on most commodities have been successfully reduced over decades of multilateral and preferential trade negotiations, NTMs are among the main remaining impediments to free trade and therefore have become an important subject of CGE-based trade policy analysis.

A taxonomy developed by UNCTAD classifies NTMs into sixteen general categories. Three are defined as technical measures. Sanitary and phytosanitary (SPS) regulations, such as inspection and quarantine requirements, are designed to ensure food safety and prevent the dissemination of disease or pests across countries. Technical barriers to trade (TBTs) include labeling and certification requirements, technical and quality standards, and environmental measures. A third technical category includes pre-shipment inspections and customs formalities. In addition to technical measures, other NTMs include commercial policies such as quantity quotas on imports or exports, rules of origin that restrict imports by one country from its trade partner if a good is mostly assembled in third countries, and behind-the-border measures such as government policies that restrict government purchases to domestically produced goods (public procurement).

Technical Non-tariff Measures in International Trade

Our discussion of NTMs in this chapter focuses on technical measures, whose proliferation in recent years has created concerns that the measures are being introduced as a form of disguised protection as import tariffs have come under greater discipline. Addressing technical measures in ways that both liberalize trade and safeguard the health and safety of consumers and the environment has become one of the core tasks in today's trade negotiations.

CGE modelers are grappling with the problem of how to represent the effects of technical non-tariff measures on import competition and the efficiency with which goods are transported across national borders. A technical NTM provides protection from competition if it restricts the volume of imports, even when the regulation is not intended to be protectionist. For example, a Canadian SPS measure may require Canadian importers to provide additional certifications for imports of Mexican avocados if Mexico is experiencing a pest infestation. By increasing import costs, the SPS measure reduces trade volumes and the import competition faced by Canadian growers, although its objective is to protect the health of Canadian plant life.

The scarcity caused by a reduction in trade volume can generate *economic rents*, or excess profits, for importers or for exporters. Canadian avocado importers, for example, can now charge a higher domestic price for Mexican avocados because of their scarcity in the Canadian market. This price wedge between the domestic and world avocado prices is similar to the price wedge created by an import tariff. Or, if Mexican exporters can now charge a higher export price for avocados because of their reduced volume of exports, the price wedge between their domestic supply price and their world export price is similar to that created by an export tax. But whereas tariff revenues are collected by the government, economic rents are captured by the private importer or exporter, depending on how the NTM is administered. The price wedge caused by a technical NTM may not only reflect economic rents but could also result from *trade inefficiencies* if time and resources are wasted at the border. For example, inventory deterioration due to added customs formalities results in a loss of product during border transit.

CGE modelers make the analysis of technical NTMs more analytically tractable by first converting the regulations into an *ad valorem equivalent (AVE)* tax. The AVE tax rate is equivalent to the regulation if the introduction of the tax has the same impacts on market price and quantity as the introduction of the technical measure. The conversion first requires that the CGE modeler econometrically estimate or calculate the NTM's market impact.

To do so, some modelers estimate gravity models to measure the regulation's trade quantity impact – that is, they econometrically estimate what the import quantity would be without the regulation in place. They next combine their findings on the difference in quantities with and without the regulation with information about price elasticities of import demand, to calculate an import tariff rate that would result in an equivalent quantity gap as the regulation. Other modelers instead use a price gap method in which they compare prices across countries that have or do not have the NTM, or at different points along a country's supply chain. These price comparisons allow them to determine what the market price would be without the regulation in place. They use that price markup to calculate a tax rate of an equivalent percentage. In most gravity or price gap studies, technical measures are expressed in terms of their equivalence to an import tariff rate.[1]

The modeler then divides the AVE of the NTM into components that describe the shares of the price wedge that accrue to importers or exporters as economic rents, or result from trade inefficiency. The share of the AVE of the NTM that is captured by the importer as economic rents is represented in the CGE model as an import tariff (Table 9.1). The share that is captured by exporters as economic rents is represented in the CGE model as an export tax. For example, assuming zero trade efficiency effects, if the regulation's estimated AVE of an import tariff is 10%, and importers and exporters are assumed to share equally in the distribution of its economic rents, then a 5% surcharge is added to the importer's existing import tariff for that good, and a 5% surcharge is added to the exporter's existing export tax for the good. The CGE model database is then updated by an experiment that adds the surcharges to import tariffs and to export taxes before any trade policy experiments are implemented.

The share of the NTM's AVE that is due to resource-wasting trade costs and inefficiencies is sometimes called "sand in the wheels." It is typically

[1] Deardorff and Stern (1997) and Ferrantino (2006) provide comprehensive discussions of how the economic impacts of NTMs can be quantified as AVEs of a tax.

Table 9.1. *Approaches to Modeling Technical NTMs in a Standard CGE Model*

	CGE model representation		
	Export tax	Import tariff	Trade efficiency (iceberg trade costs)
Market effect	Economic rents that accrue to the exporting country, compliance costs for exporter	Economic rents that accrue to the importing country, compliance costs for importer	Resource-wasting trade costs
CGE database update?	Yes – add AVE as a surcharge to existing export tax	Yes – add AVE as a surcharge to existing import tariff	No – the introduction or removal of an NTM is described in a model experiment as a change in the efficiency of transporting goods from exporter to importer

represented in a standard CGE model as an *iceberg trade cost*.[2] As an example, assume that a technical measure related to apple imports requires more intensive inspections of apple containers in the port. Some part of the apple shipment will rot because of these extra delays; some apples, in effect, "melt" away during the border crossing just as an iceberg melts as it moves across the ocean. As a result, the exporter sends the same quantity of apples, for the same world price, but the importer receives fewer apples at that price. That is, trade efficiency has fallen because the same quantity of exports now yields a smaller quantity of imports. Another way to express it is that the apple export quantity is unchanged but the *effective import quantity*, defined as the original export quantity minus the iceberg loss, has declined. And since the importer now receives a smaller quantity of imports for any given world price, the *effective import price* has increased.

Unlike the tariff and tax surcharges, a CGE model database is not updated to include trade efficiency effects, because the initial model equilibrium described in the SAM implicitly accounts for efficiency levels in the initial quantities and prices. A regulation's trade efficiency effects are only introduced as an experiment that describes a change in the technical measure. If, for example, our estimated 10% AVE of the technical NTM is due solely to

[2] This is sometimes called a "Samuelsonian" trade cost because the concept was first utilized in a trade model by Samuelson (1954). The seminal literature on the inclusion of iceberg trade costs in a standard CGE model include Hertel et al. (2001), Fox et al. (2003), Andriamananjara et al. (2003) and Fugazza and Maur (2008).

Text Box 9.1. Non-Tariff Measures in a Preferential Trade Agreement

Agriculture in the Transatlantic Trade and Investment Partnership: Tariffs, Tariff-Rate Quotas, and Non-Tariff Measures (Beckman, Arita, Mitchell, and Burfisher, 2015).

What is the research question? The United States and the European Union are negotiating an ambitious trade agreement that would address not only a reduction of tariffs and subsidies, which are already low, but also reduce barriers posed by protectionist non-tariff measures, which are especially prevalent in agriculture. How important is the successful removal of NTMs in achieving the full benefits of the pact on agricultural trade between the two economies?

What is the model innovation? Beckman and his team implement gravity models to estimate the ad valorem import tariff equivalents of selected NTMs that have been identified by the trade partners as protectionist impediments to bilateral trade. They then use a detailed supply-chain approach to study the incidence of each of the NTMs' price impacts and to allocate their AVEs as surcharges to export taxes or import tariffs, or as trade efficiency costs. For example, one-third of the AVE of the EU NTM on biotech corn is assigned to trade inefficiencies and two-thirds is assigned the U.S. export tax; no NTM costs are assigned to the EU import tariff.

What is the experiment? They model two scenarios: the "market access scenario" removes tariffs and increases TRQ quota amounts by 50%; the second scenario adds a complete removal of NTMs to the market access scenario.

What are the key findings? The authors find that total EU-U.S. agricultural trade increases by $4.5 billion in the market access scenario. The additional removal of NTMs delivers substantial further gains in bilateral agricultural trade, worth $2.3 billion, however binding TRQs limiting some of the potential gains from NTM reforms.

trade inefficiency, then removal of the measure is described in an experiment as a 10% increase in trade efficiency.

A modeler must draw on a well-grounded institutional knowledge of how an NTM is implemented to accurately allocate the AVE of the tax across the three mechanisms in a CGE model. (See Text Box 9.1 for an example of how a supply-chain analysis is used to guide this allocation.) An exploration of these three alternatives in theoretical models will illustrate the importance of this allocation to your analytical results. Figure 9.1a describes the effects on the importer's economy of the introduction of a technical NTM that is represented in a standard CGE model as an ad valorem import tariff. Figure 9.1b illustrates the effects on the exporter's economy of a new technical NTM that is represented in the model as an ad valorem export tax. In both figures, the compensated demand curve, D^1, describes the initial import demand and S^1 is the initial export supply curve. We adopt the Armington assumption

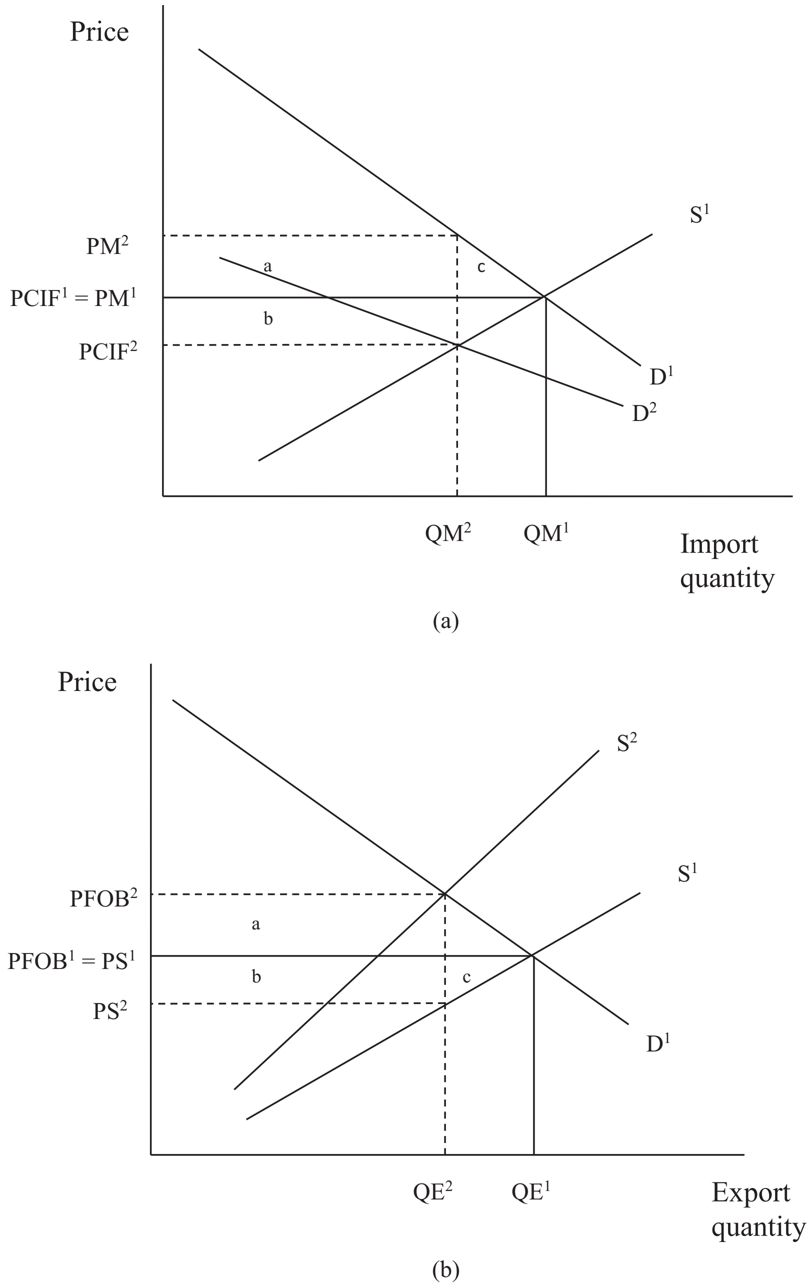


Figure 9.1. (a) Effects of a technical NTM modeled as an AVE of an import tariff. (b) Effects of a technical NTM modeled as an AVE of an export tax.

that there is no domestic production in the importing country of the imported variety, and the assumption that there is no domestic consumption of the exported variety in the exporting country. To simplify, we also assume there are no transport costs or other taxes in the initial equilibrium.

In Figure 9.1a, QM^1 is the initial equilibrium import quantity, and the initial equilibrium *cif* import price ($PCIF^1$) is equal to the domestic consumer price of the import (PM^1). Similar to an import tariff, the NTM's introduction rotates the import demand curve from D^1 to D^2. The vertical distance between the two curves measures the per-unit economic rent that is generated on a given quantity of imports. In the new equilibrium, the consumer price of the import increases from PM^1 to PM^2, and the quantity of imports falls to QM^2. Area *c* measures the uncompensated loss in consumption efficiency in the importing country due to the decline in imports. Economic rents are measured by area $a + b$. Similar to tariff revenues, they are distributed within the importing country so do not affect welfare. The decline in import demand yields a terms-of-trade gain to the importer, shown as area *b*, as its world import price falls to $PCIF^2$. The net effect on the importing country's welfare depends on whether the gain in its terms of trade (area *b*) exceeds the loss in its consumption efficiency (area *c*).

Figure 9.1(b) describes the effects on an exporter of a technical measure that is represented as an ad valorem export tax. In the initial equilibrium, the country exports QE^1 at the *fob* world export price ($PFOB^1$) which, in the absence of export taxes, equals the exporter's producer price (PS^1).

The introduction of a technical NTM that generates rents for the exporter is shown as a rotation in the export supply curve from S^1 to S^2. The vertical distance between the two supply curves measures the per-unit rent generated by the NTM on a given export quantity. In the new equilibrium, quantity QE^2 is exported, the export price increases to $PFOB^2$, and the producer price falls to PS^2. Area *c* measures the exporting country's uncompensated loss in production efficiency as output falls. Area $a + b$ looks much like the direct burden of an export tax. In this case, it measures the economic rents that are distributed within the exporter's economy. Area *b* compensates producers for part of their loss in producer surplus and area *a* describes the exporter's terms-of-trade gain on quantity Q^2 of exports. The net effect on the exporter's welfare depends on whether the gain in its terms of trade (area *a*) exceeds the loss in its production efficiency (area *c*).[3]

Figure 9.2 describes a technical NTM that causes a loss in trade efficiency due to iceberg trade costs. In the figure, the demand curve, D, describes import demand and S^1 is the initial import supply curve. In the initial equilibrium, QM^1 is the imported quantity and, assuming zero initial trade costs, the

[3] Notice that Figures 9.1a and 9.1b each contain only one deadweight loss triangle. That is because we assume in Figure 9.1a that there is no domestic production of the imported good, so there is no loss of producer surplus. In Figure 9.1b we assume there is no domestic consumption of the exported good, so there is no loss of consumer surplus.

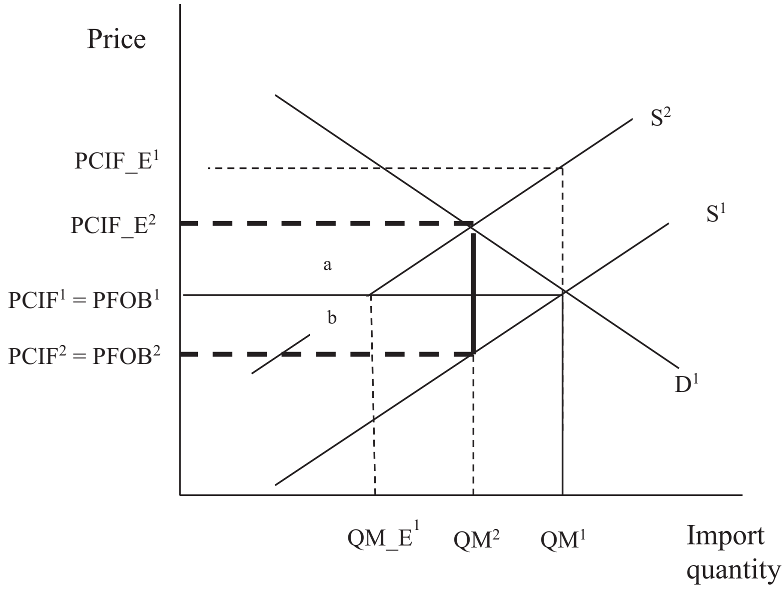


Figure 9.2. Effects of a technical NTM modeled as a trade efficiency loss.

importer's initial *cif* import price ($PCIF^1$) is equal to the exporter's initial *fob* export price ($PFOB^1$).

From the importer's point of view, a technical NTM that imposes iceberg trade costs reduces the effective quantity of the import received at price $PCIF^1$ and results in a new, effective import supply curve, S^2. The per-unit cost of the NTM is described by the vertical distance between the two supply curves. At quantity QM^1, the exporter still charges $PFOB^1$ per unit but the importer now pays an effective import price of $PCIF\_E^1$ because of the added cost of the NTM. The per-unit iceberg trade cost, expressed in terms of the quantity of good QM, is described by the horizontal distance between the two supply curves. At the export price of $PFOB^1$, the exporter still sells the same quantity, QM^1, but the importing country now receives only the effective quantity of QM_E^1. Quantity $QM^1 – QM\_E^1$ has been used up (or "melted away") in the transport of QM^1.

The decline in the effective import supply means that the importer would need to increase its actual imports to enjoy the same level of imports as in the initial equilibrium. On the other hand, the increase in the effective import price causes the quantity of imports demanded to fall. In the new equilibrium, at the intersection of the import demand curve and the effective import supply curve, S^2, the importer's effective import price has increased to $PCIF\_E^2$ from its initial *cif* import price and the quantity of actual imports demanded falls from QM^1 to QM^2.

The rectangular area $a + b$ in the figure measures the trade efficiency costs caused by the technical NTM in the shipment of quantity QM^2 from the exporter to the importer. Rectangle b measures the terms-of-trade loss to the exporter due to the decline in its export price from $PFOB^1$ to $PFOB^2$, which compensates the importer for part of the trade efficiency loss.

We explore these ideas empirically using the GTAP model with the US3×3 database. Our experiment is the elimination of a technical NTM enacted by the United States on its manufacturing imports from the rest-of-world. Let's assume that we are drawing on the results of a gravity model that describe the technical NTM as having an equivalent effect on markets as a 2% U.S. bilateral import tariff on manufactured imports from the rest of the world. To draw a sharp contrast, we first assume that the protective effect of the NTM only generates economic rents that are captured entirely by ROW exporters. We update our model in an experiment that increases the export tax on ROW's manufactured exports to the United States by two percentage points. We save the output of this update as a new CGE model version. We next assume that the technical NTM only generates economic rents that are captured entirely by U.S. importers. In this case, we update our model with an experiment that increases the U.S. import tariff on manufactured imports from the rest of world by two percentage points, saving this output as a second updated model version. Finally, we assume that the technical NTM only impacts trade efficiency, for which we do not need to update our model. Our three trade liberalization experiments are applied to the three separate model versions to (1) remove the AVE of the export tariff from the first updated model, (2) remove the AVE of the import tariff from the second updated model, and (3) increase manufacturing trade efficiency by 2% in the base US 3×3 model version.

Model results are reported in Table 9.2. Whether the U.S. technical NTM on manufacturing is described as a surcharge to the ROW's export tax or to the U.S. import tariff, its removal increases the quantity of U.S. imports and causes the domestic price of the imported good in the United States to fall. However, welfare results between the two approaches differ markedly. Removal of an NTM modeled as a reduction in the ROW export tax increases U.S. welfare, in part because it increases ROW's supply of manufacturing exports, causing its *fob* export price on its U.S. sales to fall and the U.S. terms of trade in manufacturing to improve. Removal of an NTM modeled as a U.S. import tariff reduces U.S. welfare, in part because it increases U.S. demand for manufacturing imports from ROW, causing ROW's *fob* export price to rise and the U.S. terms of trade to deteriorate. These stark differences in welfare outcomes illustrate the importance of the modeler's decision about the allocation of an NTM's ad valorem tax equivalent between import tariffs and export taxes.

Table 9.2. *Effects of the Removal of a U.S. Technical NTM on Manufactured Imports from ROW, with a 2% AVE of an Import Tariff Modelled in Three Alternative Ways*

	AVE of 2% U.S. import tariff in manufacturing modeled as		
	(1) ROW export tax	(2) U.S. import tariff	(3) Iceberg trade efficiency cost
Changes in trade quantities and prices (% change)			
Quantity of ROW exports of MFG to the United States (*qxs*)	3.98	3.18	1.67
Effective quantity of U.S. imports from ROW (*qxs* + *ams*)	3.98	3.18	3.67
Domestic price of U.S. MFG imports from ROW (*pms*)	–1.94	–1.83	.04
Effective domestic price of U.S. MFG imports from ROW (*pms* – *ams*)	–1.94	–1.83	–1.96
ROW fob export price of MFG to United States	–2.03	0.11	.04
U.S. welfare ($U.S. billion)	31,120	–14,728	28,631
Total allocative efficiency effects	2,276	–11,791	1,540
Allocative efficiency due to U.S. MFG NTM- import tariff removal	–	13,333	–
Trade efficiency	–	–	38,031
Total terms of trade	28,844	–16,271	10,939
Manufacturing terms of trade	30,483	–8,221	–5,778
ROW welfare ($U.S. billion)	–27,787	18,315	12,287
Total allocative efficiency effects	104	2,098	1,370
Allocative efficiency due to ROW MFG NTM-export tax removal	912	–	–
Trade efficiency	–	–	–
Total terms of trade	–28,804	16,218	10,929
Manufacturing terms of trade	–30,145	8,228	5,786

Note: Trade efficiency improvement is modeled as a 2% increase in variable ams.
Source: GTAP model with US3×3 v8 with GTAP v.8.1 database – base version and two versions with updated tax rates.

When removal of the NTM is modeled as a trade efficiency gain, the quantity of the ROW's manufacturing exports to the United States increases by only 1.67%, but the effective quantity of U.S. imports increases 3.67%. The increase in the effective import quantity is larger than for actual exports because the elimination of iceberg losses increases the quantity of the ROW's exports that successfully reach the U.S. port. This reduces the effective import price of the United States because it now receives more manufactured imports from the ROW for a given *fob* export price. As a result, the United States demands more manufactured imports, pushing up the ROW's *fob* export price and providing ROW with a terms-of-trade gain in manufacturing. Removal of "sand in the wheels" NTMs can therefore benefit both the importer, whose welfare directly benefits from the increase in trade efficiency, and the exporter, through its terms of trade gain.

These modeling techniques offer reasonable approximations of the market impacts of a technical NTM but it is important to note that these methodologies are continuing to evolve. One open question is how to allocate the AVEs of NTMs across tax and trade efficiency instruments. In addition to considering economic rents and trade efficiency losses, some modelers include certain compliance costs such as veterinary inspections or pest treatment requirements in the export tax or import tax allocation, depending on which country incurs the cost. The use of export taxes to represent exporters' NTM compliance costs may be especially appropriate in light of recent research by Beckman, et al. (2015) (described in Text Box 9.1) and Cadot and Gourdon (2015) that finds that most of the cost of NTMs is incurred before the product is exported and is already reflected in the *fob* export price.

This implementation of NTMs in a standard CGE model also has some drawbacks that a modeler should keep in mind. First, we expect that economic rents or compliance costs will accrue to the industries that supply exports, acquire imports or offer compliance services. But when a technical NTM is modeled as an import tariff or export tax, a standard CGE model treats economic rents and costs as a tax revenue flow rather than as industries' earnings. These inter-industry linkages are an important element of an economy-wide analysis of regulatory impacts. This shortcoming is particularly important in CGE models in which tax revenue is tracked directly to a government account and so directly affects government spending (whose composition likely differs from that of the private industry), the size of the government surplus and deficit, and national savings and investment.

An additional limitation of modeling the rents generated by a technical NTM as a tariff or tax is that their size can be diminished if resource-wasting, rent-seeking activities such as bribery or lobbying dissipate their value. In this case, welfare losses would include some or all of the redistributed rectangular areas that measure economic rents in addition to the deadweight efficiency losses described by area c in Figures 9.1a and 9.1b

We also have not considered the possible benefits of technical NTMs. These may be welfare-increasing if they generate societal gains such as improvements in health or the environment or if they provide consumer amenities. For example, an NTM that requires a pesticide-free certification provides food safety information that is valued by many consumers. By solving a market failure related to information about unobservable product qualities, the introduction of the technical NTM can lead to both higher import demand

and higher world import prices. In another example, consumers may be willing to pay more for a product if its delivery is timely – much as the price of a Christmas tree is higher when delivered before the holiday than in the week afterward. Walmsley and Minor (2015) use an ad valorem tariff equivalent of the willingness to pay for timely delivery in their analysis of a reduction of inefficient border practices. They extend a standard CGE model to describe the reform as a rightward shift in the import demand curve by increasing consumer preferences for those products whose border transit times improve. In this case, reducing border delays raises both the import price and the import quantity; in contrast, removal of an NTM in Figure 9.2 results in a lower (effective) import price and an increase in import quantity. Studies of the positive demand-side impacts of NTMs are still at an early stage. As yet, the social benefits of technical NTMs are difficult to quantify and monetize, so they are not typically accounted for in a standard CGE model.

Finally, some NTM compliance costs are fixed costs, such as requirements for refitting or certifying a production facility, rather than variable costs, such as product labels. Variable compliance costs rise (fall) with increases (decreases) in export quantities or prices. Fixed costs, instead, can present make-or-break economic hurdles that determine whether firms can enter or must exit foreign markets. CGE modelers have recently extended the standard CGE model framework to account for fixed export costs imposed by NTMs, building on the theoretical insights of Melitz (2003). This new generation of trade-focused CGE models is discussed in more detail in the final chapter of this book.

Regulations to Correct Negative Production Externalities

Externalities are the negative or positive spillover effects of an economic transaction between two parties on uninvolved third parties, which are not reflected in market prices. Our discussion focuses on regulations that address negative externalities that stem from production, a policy problem that is an active and innovative area in CGE-based policy analysis. A negative production externality occurs when an industry's production process has negative spillover effects whose costs are not accounted for in the industry's input or output prices. For example, an industry's use of an air-polluting technology that leads to lung disease in adjoining neighborhoods creates a negative externality. The added medical costs are a burden to the industry's neighbors, which are not taken into account in its costs of production. Negative externalities lead to market inefficiency, because industries produce more than they otherwise would if they took social costs into account. Regulations are designed to internalize the costs and benefits of externalities into agents' economic decision making.

Regulations designed to reduce production externalities may mandate either a specific production process or an outcome. *Process-based regulations* increase the cost of production because the industry must purchase a newly mandated input or technology, or practice a mandated technique. For example, a regulation designed to reduce the public health costs that result from industrial pollution could require that producers adopt a specific technology to scrub their emissions. Regulatory compliance imposes the pollution cleanup cost on the producer, which will cause the industry's output price to rise. Consumers respond by reducing the quantity demanded, so output and production of the emission falls. The reduction of the externality is therefore achieved in part through the regulation's negative *output effect* as the costs of the externality are internalized by the industry.

An *outcome-based regulation* allows producers to choose the least-cost means of achieving the regulatory goal. It may, for example, impose fixed limits on the level of the producers' emissions and allow them to find the least-cost means of complying. Producers may substitute among intermediate inputs to meet the standard or invest in research on innovative ways to achieve the mandate. For example, energy producers could substitute wind or solar energy for coal to meet new emissions regulations at a cost that is lower than installation of scrubbers. Or they may invest in research that discovers new sources of low-cost and low-emission biofuels. Outcome-based regulations can have output effects, similar to those of process-based regulations. But, because of the flexibility that they allow for *input substitution* and *technological innovation*, they may achieve the regulations' intended benefits at a lower cost than process-based regulations do.

Output effects can be readily explored in a standard CGE model, but a realistic study of the input substitution and technological innovation effects of outcome-based regulations generally calls for significant model extensions. Technical Appendix 5.1 describes an example of such extensions in a description of the addition of nests to the value-added bundle in CGE models used to analyze climate change mitigation. Yet, even with its limitations, a standard CGE model, such as our toy US3×3 version, remains a useful tool for study and demonstration because it introduces you to many of the core concepts in regulatory policy analysis, which you can draw on as you advance your skills in working with more complex, regulatory-focused CGE models.

Let's first explore the theory underlying the analysis of a regulation. Figure 9.3 describes an industry whose production results in a negative externality. For example, it may be an industry that dumps harmful waste products into a river, which causes an increase in the nearby town's water treatment costs. In the figure, D is the demand curve or, equivalently, the marginal social benefit (MSB) derived from consumption of the industry's products. S^1 is the industry's supply curve. It describes the industry's marginal private

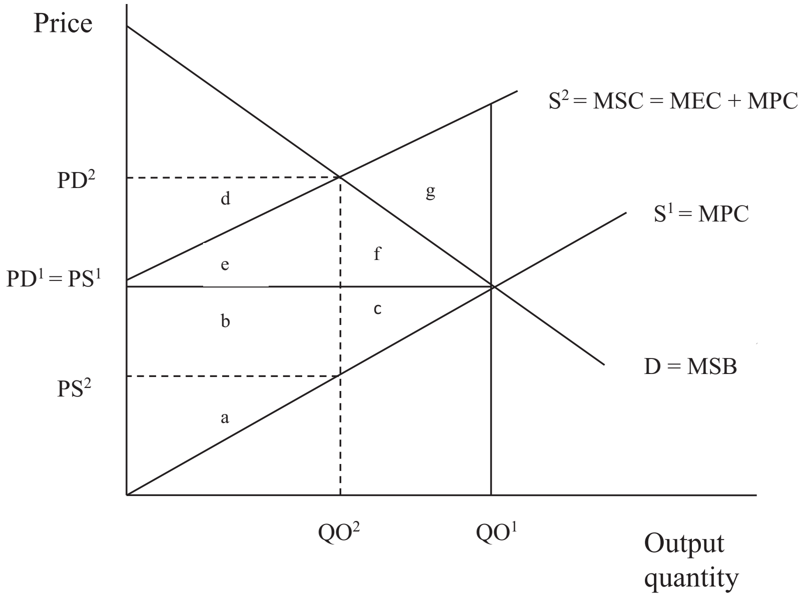


Figure 9.3. Effects on the domestic market of a regulation to correct a negative production.

cost (MPC) of production, which excludes the cleanup costs that its water-polluting production process currently imposes on the town. Assuming that the costs of cleaning up the pollutants are constant per unit of output, then S^2 describes the marginal social cost (MSC) of production; it adds the marginal external cost (MEC) of civic water treatment to the industry's private costs of production. QO^1 is the initial market equilibrium output for the unregulated industry and, assuming no sales taxes, the initial producer price, PS^1 is equal to the initial consumer price, PD^1.

From a societal perspective, PS^1 and $QO^1$are not an efficient equilibrium. For all quantities above QO^2, too much of the good is being produced and consumed because the marginal social cost of the good's production exceeds the marginal social benefit from its consumption (MSC > MSB at all quantities above QO^2). The area measured by $a + b + c + e + f + g$ describes the total external costs to society from producing QO^1. Because areas $a + b + c$ are gained in producer surplus, and areas $e + f$ are recouped in consumer surplus at price P^1, area g represents the uncompensated external cost loss to society from the excess production of QO^2–QO^1.

Assume that a regulation is introduced that requires the industry to clean up its waste products before dumping them. The regulation might, for example, require the purchase and use of water filters. If we assume that the newly required process is the least-cost method, then the industry's marginal private cost curve shifts up from S^1 to S^2 as the marginal external costs are internalized by its expenditures on the new technology. The higher cost of production leads to a higher consumer price, PD^2, and a lower quantity of production, QO^2. Price PS^2 is the producer price net of the cleanup expenditure. In the new market equilibrium, consumers face a loss in surplus described by area $d + e + f$. Producers lose the surplus described by area $a + b + c$, but gain area d. The added cost to producers from cleaning its emissions is the sum of areas $a + b + e$. Similar to the redistribution of tax revenue to the government, these added compliance costs are not lost to the economy because the expenditures are redistributed from the regulated industry to the industries that supply the mandated services or equipment. The net cost of the regulation is thus the uncompensated loss of production and consumption efficiency described by area $f + c$.

We must also take into account, however, that the regulation has prevented some water pollution by reducing output. The area $f + c + g$ measures the social benefit that results from this output effect. An important question in this analysis is whether the benefits of the required water treatment are at least as large as its efficiency costs to the economy. After deducting the losses in producer and consumer surplus ($f + c$), area g measures the net social benefit of the regulation with an equilibrium output of QO^2 and a consumer price of PD^2. As drawn, our graph indicates that this regulation is a socially worthwhile policy.

The compliance costs depicted in Figure 9.3 illustrate one reason why a general equilibrium perspective is needed in regulatory policy analysis. The compliance expenditures will expand output and employment in the "green" industries that provide pollution control services, offsetting the decline in output in the regulated industry.

There are several other reasons why CGE models are well suited to the analysis of negative production externalities. Factors in addition to compliance costs also contribute to changes in industry composition – for example, a regulation is likely to affect national income and therefore the quantities and types of goods that consumers demand as their incomes change. Also, changes in a country's export supply and import demand may lead to macroeconomic effects, such as a change in its exchange rate, which affects all tradable industries in the economy. Such general equilibrium impacts on *industry composition* can lead to either lower or higher total production of externalities, depending on whether and how much pollution is emitted by the other industries in an economy.

Some researchers who focus on environmental regulations have explored the problem of *second-best efficiency effects* that can result from the interaction of the regulations with an economy's existing taxes.[4] For example,

[4] A useful reference on this topic is Paltsev et al. (2004), who provide a graphical illustration of second-best and terms-of-trade effects of environmental policies. Goulder et al. (1998) develop a comprehensive review of the literature on second-best interactions with environmental policy, and

a regulation that leads to lower output in a subsidized industry will have a welfare-enhancing effect if it reduces the inefficient overproduction that resulted from the subsidy. Another concern is the possible negative impact on global competitiveness and export demand of regulations that increase the production costs of regulated industries relative to unregulated foreign industries. Compliance costs that increase export prices can cause demand for the exports of the regulated country to fall, and this in turn can lead to changes in the *terms of trade*.[5]

The efficiency losses in a regulated market, described by areas *f* and *c* in Figure 9.2, are the *direct costs* of a regulation.[6] A regulation's general equilibrium effects on industry composition, second-best efficiency and terms of trade describe its *indirect costs*.

CGE researchers have generally taken two approaches to describe the introduction of regulations into a model. One is the productivity approach, which describes the increase in production costs due to the mandated purchase of newly required inputs. For example, a health regulation may require a cattle producer to provide veterinary certifications for each steer that is sold. This can be modeled as a decline in the productivity of that veterinary service input or as an increase in the input-output coefficient for the required service that is used as an intermediate input into cattle production. In either case, production costs rise because a greater quantity of some input is required to produce the same quantity of output.

Outside research on the cost of compliance and, ideally, on the type of newly required input is needed to accurately define an experiment that realistically describes the cost to producers of a regulation. Let's assume that our external research informs us that regulatory compliance increases the quantity of the cattle producer's input requirements for services by 2%. We could then describe the regulation's effect in our model as a 2% decline in the productivity of the services input used in the production of cattle. Text Box 9.2 describes an analysis of new corporate governance regulations that require some private companies to increase their purchases of auditing services. The regulation is modeled as an increase in the input-output coefficient for services used in the production technology of the regulated industries (Chisari et al., 2014).

compare the second-best effects of process-based regulations (an emission-reducing, mandated technology) with other types of environmental policy instruments.

5 In practice, the anticompetitive impacts of environmental regulations have not proven to be notable, in part because compliance costs are usually a small share of total production costs (Dean, 1992).

6 The term *direct costs* commonly used in the CGE-based regulatory literature should not be confused with the term *direct burden* used in the public finance literature described in Chapter 8. In the regulatory literature, direct costs are the regulated industry's deadweight efficiency losses due to a regulation; in the public finance literature, direct burden refers to tax or tariff revenue that is redistributed to the government and so is not a loss to the economy.

Text Box 9.2. Modeling Regulations as an Input Productivity Shock

"Could Corporate Governance Practices Enhance Social Welfare?" (Chisari, Ferro, Maquieyra et al., 2014).

What is the research question? Following the global financial crisis, many governments imposed new regulations to improve corporate governance and reduce risks for investors. Resources must be used to comply with these new controls, but reduction of corporate risk also may reduce the cost of capital. What are the costs and benefits of the new regulations?

What is the CGE model innovation? Chisari and colleagues develop a recursive dynamic CGE model of Argentina as a case study. The model describes the benefits of regulations as a change in the cost of capital, measured as a change in the price of bonds that are purchased by private households and bought and sold by the government. The model accounts for the costs of the regulations based on data on actual additional auditing expenditures. These costs vary by sector and are implemented as a change in the input-output coefficient on audit services used as intermediate inputs by the regulated industries.

What is the experiment? The team carries out four experiments: (1) an increase in audit costs, (2) an increase in audit costs accompanied by a permanent 1% reduction in the price of bonds, (2) an increase in audit costs with a temporary 1% reduction in bond prices, and (4) an increase in audit costs with volatile changes in bond prices.

What are the key findings? Regulatory compliance in itself is costly because the economy is diverting resources from capital accumulation to pay for the extra audit expenses; this leads to a small reduction in GDP growth. But if the reforms succeed in achieving even a modest long-run reduction in capital costs, then corporate governance is worthwhile, even if this reduction is transient. However, volatility in the cost of capital reduces the benefits of stronger corporate governance.

A second CGE modeling approach describes a regulation by imposing quantities, such as a cap on the use of a polluting input, and allowing a "shadow tax" to adjust relative prices until this constraint is met. The industry internalizes the social cost of the externality by paying both the market price (PS^2) plus the shadow tax ($PD^2 - PS^2$)in Figure 9.3 on the regulated input. For example, the modeler can place a cap on the quantity of coal used as an input into energy production, and solve for the shadow input tax that achieves this outcome. This approach requires a change in the closure of a standard CGE model. The exogenous sales tax rate on the input is defined as endogenous. The quantity of the input is defined as exogenous and is reduced in the regulatory policy experiment. The solution value for the endogenous shadow tax is calculated as the new input tax rate minus the initial tax rate. The shadow tax rate can be interpreted as the marginal cost of compliance,

Text Box 9.3. Input Substitution and Technological Innovation in a CGE-Based Regulatory Policy Analysis

"Assessment of U.S. Cap-and-Trade Proposals" (Paltsev et al., 2007).

What is the research question? The United States wants to lower greenhouse gasses emitted by energy sources, including coal, petroleum, and gas. How might emission reduction policies affect levels of energy use, substitution among energy sources, and technological innovations that reduce emissions per unit of energy produced?

What is the CGE model innovation? The team developed a recursive dynamic CGE model that provides producers with the flexibility to switch among fifteen energy sources that are characterized by varying degrees of substitutability. Technological changes over time include increases in factor supplies, decreases in emissions per unit of output, and increased use of unused or minimally used alternative energy sources as they become economically competitive.

What is the experiment? A suite of experiments describe various energy policy options, including higher or lower caps on emissions. Caps are imposed by placing constraints on aggregate emissions and solving for a shadow price, or an endogenous tax wedge, that represents the price at which carbon permits would trade and generate revenue for economic agents.

What are the key findings? Results compare the equivalent variation welfare costs of alternative emission reductions policies, decomposing welfare effects into direct and indirect costs. Direct costs are the abatement costs, estimated to range between \$120 to more than \$200 by 2050 per unit of CO_2. Total welfare costs, which include the indirect benefit resulting from terms-of-trade gains, are estimated to rise between 1.1% and almost 2% by 2050. Results are sensitive to assumptions about future technological change. An optimistic technology scenario would reduce the costs of abatement whereas a pessimistic scenario would drive abatement costs higher. No assessment was carried out of the economic effects of climate change avoided or ancillary benefits of emissions mitigation, but these benefits would provide at least a partial offset to mitigation costs.

or the cost of avoiding an additional unit of the externality, and the shadow tax revenue (area $b + e + d$ in Figure 9.3) is the cost of regulatory compliance that is redistributed within the economy. The shadow-tax approach is used in the MIT-EPPA model, a CGE model with a rich, nested structure that allows substitution among intermediate inputs in the production of energy (Paltsev et al., 2007). Their study of an outcome-based regulation of greenhouse gas emissions accounts not only for the output effect but also for a substitution effect, which allows producers to shift among cleaner or dirtier sources into the energy input, and for technological innovation (see Text Box 9.3).

For demonstration, we implement the shadow tax approach using the GTAP CGE model and the US3×3 database. We emphasize that it is a highly stylized example because our model describes only output effects, without intermediate input substitution possibilities or technological innovation. Yet, our experiment is still worthwhile because it allows us to explore the two key concepts of the direct and indirect costs of a regulation.

Let's assume that a regulation is introduced in the United States. Its objective is to require manufacturers to reduce the externality that results from their production process by 1%. Our experiment's design stems from our model structure, in which we assume a Leontief fixed input-output relationship for intermediates. Therefore, the percentage change in any intermediate input is equal to the percentage change in output of the final good. Instead of capping the quantity of a specific dirty input used in manufacturing production, our experiment therefore directly regulates the quantity of manufacturing output. To do so, we first change the model closure to make U.S. manufacturing output an exogenous variable and its output tax rate an endogenous variable. Our experiment imposes a 1% reduction in U.S. manufacturing output and our model solves for the output sales tax that achieves this objective.

The regulatory requirement for U.S. manufacturers is achieved at a marginal cost of compliance, or a shadow tax, equal to an output tax rate of 2.2% (Table 9.3). The $146 billion in shadow tax revenue is the added cost of compliance (area $d + e + b$ in Figure 9.3), which is redistributed throughout the economy. Higher production costs lead to a 1% increase in the price that consumers pay for manufactures (price PD^2 in Figure 9.3), but the producer price, net of their compliance costs, falls by 1.2% (price PS^2 in Figure 9.3). Output falls by 1% as consumer demand responds to the increase in the consumer price. Despite its new regulatory burden, U.S. manufacturing exports increase and its imports decrease. This is due in part to the substantial U.S. real exchange rate depreciation, a general equilibrium effect of the regulation.

The direct cost of the regulation, of almost $1.5 billion, is the loss in allocative efficiency (area $c + f$ in Figure 9.3) in the manufacturing sector due to the shadow tax rate, or marginal compliance cost. The regulation's indirect costs include changes in the economy-wide production of the externality that result from changes in the industry composition of the U.S. economy. Given our Leontief technology, we can assume that any changes in use of dirty inputs by agriculture and services are identical to the changes in their output, which increase in both industries. Indirect costs also include $5.2 billion in second-best allocative efficiency losses related to other U.S. taxes, and a terms-of-trade loss of $33 billion. The total welfare impact of the regulation includes the regulation's direct cost, second-best efficiency effects, and terms-of-trade changes. It is a loss of nearly $40 billion to the United States. An important caveat to our study is that our model's Leontief technology does

Table 9.3. *Effects of a Regulation to Correct a Negative Externality in U.S. Manufacturing*

Effects on U.S. manufacturing	
Shadow tax rate on manufacturing output (percent)	2.2
Shadow tax revenue ($US millions)	146,454
Production of externality (% change) (*qo – MFG*)	–1.0
Market price (% change) (*ppd*)	1.0
Producer price (% change) (*ps*)	–1.2
Export quantity (% change) (*qxw*)	0.9
Import quantity (% change) (*qiw*)	–1.9
Real exchange rate (% change) (pfactor)	–3.26
Direct cost – allocative efficiency effect in manufacturing ($US millions)	–1,456
Indirect costs	
Production of externality in agriculture (% change) (*qo*)	1.4
Production of externality in services (% change) (*qo*)	0.2
Second-best allocative efficiency effects ($US millions)	–5,169
Terms of trade($US millions)	–33,009
Total U.S. welfare ($U.S. millions)	–39,634

Note: The shadow tax rate is calculated as the difference between the initial and new output tax rates. Shadow tax revenue is calculated as the product of the updated value of output (VOM) and the shadow tax rate. Direct cost is the allocative efficiency effect linked to the change in output tax in U.S. manufacturing. Second-best efficiency effects are calculated as the total allocative efficiency costs minus the direct cost.
Source: GTAP model, GTAP v.8.1 U.S. 3×3_v8 database.

not allow input substitution – perhaps between "dirty" inputs and "clean" intermediate inputs into manufacturing; if feasible, such substitution could reduce the costs of achieving the regulatory target. Also, we assume that no technological change occurs that could reduce the externality created per unit of dirty inputs – this too, could reduce the costs of complying with the regulation.

An important missing element in this analysis is a calculation of the net benefit to the United States from reducing production of the externality. Regulations are usually enacted in order to achieve societal benefits, but it can be difficult to calculate their value. Benefits from reducing an externality could be measured in terms of the externality, such as tons of CO_2 emissions that are avoided or the number of lives saved. In some cases, the benefits described by area $c + f + g$ in Figure 9.3 can be monetized. For example, the number of lives saved may be translated into dollar values. In our example regulation, the net benefit to society from the regulation in manufacturing could be calculated by subtracting direct costs and indirect costs from a monetized value of its benefit. However, despite the importance of including the value of benefits in a full consideration of regulation, they are not typically accounted for in CGE analyses.

Summary

Our study of regulatory policies in a CGE model focused on technical non-tariff measures affecting trade and on regulations designed to correct negative production externalities such as pollution. Studies of these two types of regulations are among the most timely applications and innovative modeling fields in current CGE-based research. Our examination of each type of regulation began with a simple, partial equilibrium, theoretical model that illustrated how these nonprice policy mechanisms influence resource allocations, economic efficiency, and welfare; and our discussion developed insights into their general equilibrium impacts. We described the three mechanisms for introducing a technical non-tariff measure into the CGE model: as a surcharge to an import tariff or to an export tax, or as a change in trade efficiency. We described process-based and outcome-based regulations; their output, substitution, and innovation effects; their direct and indirect impacts; and how to calculate their net benefits to society. We provided highly stylized, applied applications using a standard CGE model to demonstrate methodologies, introduce core concepts, and illustrate the capabilities and limitations of standard CGE models in regulatory policy analysis.

Key Terms

Ad valorem equivalent of a non-tariff meausure
Direct cost of regulation
Effective import price
Effective import quantity
Externality
Iceberg trade cost
Indirect cost of regulation
Input substitution effect
Non-tariff measure (NTM)
Outcome-based regulation
Output effect of regulation
Process-based regulation
Regulation
Rent (economic)
Substitution effect of a regulation
Technological innovation effect
Trade efficiency

PRACTICE AND REVIEW

1. Assume that a shipment of fresh strawberries is delayed at the border because of a technical non-tariff measure, and that some share of the strawberries becomes

moldy because of the delay. Explain how this can lead to a trade efficiency loss. In a graph, describe its effects on actual and effective demand for imports, the exporter's price of strawberries and the importer's effective price of strawberries.

2. Assume that a new regulation requires a chemical company to clean up the toxic residues in its plant waste. In a graph, describe the effects of the regulation on consumers, producers, compliance costs, and welfare. Label the axes, curves, and initial market equilibrium. As drawn, does this regulation yield a net welfare gain to this society? What variables in your CGE model correspond to the costs and welfare impacts of the regulation shown in your graph?
3. Explain the difference between a process-based and an outcome-based regulation, defining the output, substitution, and technological innovation effects. Define the direct and indirect costs of a regulation.

10

Conclusion: Frontiers in CGE Modeling

Computable general equilibrium (CGE) models are sometimes criticized for being "black boxes" in which so many things are moving at once that results are difficult to explain and their credibility as a theoretically consistent, analytical tool is undermined. By deconstructing a standard CGE model with the aid of basic principles of economics, we hope to have dispelled some of their mystery and made them more comprehensible and useful to students and professional economists alike. Such an introductory study seems especially timely given the increased accessibility of CGE models and CGE model databases.

In this book, we studied the main components of a CGE model. We learned that producers in the model are assumed to maximize efficiency, and consumers are assumed to maximize utility. Their microeconomic behavior adds up to the macroeconomic performance of the economy. Our study of each component of the model – supply, demand, factor markets, trade, and taxes – emphasized the model's underlying economic theory and supplied practical examples from small-scale CGE models to illustrate these concepts.

We studied a "standard" CGE model that assumes a representative household consumer, a representative producer of each type of product, and uniquely determined solution values for prices and quantities. It is a static, or single-period, model that provides a before-and-after comparison of an economy after a shock, such as a new tax, but it does not describe the economy's adjustment path from the old to the new equilibrium. All of these features of our CGE model can at times represent shortcomings or constraints. The aggregation of all households, despite the great diversity in their income sources and tastes and preferences, into one representative household consumer is quite a strong assumption. Producers, too, may be diverse in ways that are important to an analysis, perhaps producing the same product using different types of technologies or facing very different transportation costs in different regions of a country. In addition, our world is characterized by some amount of randomness, like weather variability, and this stochasticity is not reflected in our deterministic CGE model. Static models also may not fully address the concerns of policymakers about the transition process, when there can be high unemployment or other types of dislocation as an economy adapts to shocks. Economists working in more sophisticated and frontier areas of CGE modeling have extended the models' capabilities in all of these dimensions. Your foundation in working with a standard CGE model now leaves you well prepared to appreciate the significance of these advances.

CGE modelers have addressed the problem of how to disaggregate representative households in two different ways. One approach is to decompose the single household account in the Social Accounting Matrix (SAM) and in the CGE model into multiple accounts, in which sources of factor income and the baskets of goods purchased by each household type differ. In this way, a shock such as the decline in one industry's employment will directly affect only households whose income derives from that sector. Likewise, a tax on capital income would affect households with significant dividend income more than it would households with mainly wage income.

A second approach is to link the CGE model with a "micromodel" that may contain thousands of households. The micromodel includes estimated behavioral equations, usually based on national household survey data, which describe how households' hours of work and quantities of consumption respond to changes in wages, prices, and income. The endogenous price and income results of the CGE model, the "macromodel," are then incorporated into the micromodel as exogenous shocks, which results in responses at the household level. With this approach, the distribution of macro effects across households does not feed back to influence production, employment, or other variables in the CGE model. Macro-micro models have made important contributions to the analysis of the distributional effects of policies on household income and poverty (e.g., Bourguignon, Robilliard, and Robinson, 2003, summarized in Text Box 4.2; Hertel et al., 2004b; Verma and Hertel, 2009, summarized in Text Box 10.1).

Extensions of CGE models to describe diversity among producers are similar in many respects to the disaggregation of the representative household. One approach is to differentiate industries by adding additional industry accounts to the SAM, as in Block et al. (2006) and Diao et al. (2008). For example, agricultural production of each commodity could be differentiated by region, so that the SAM has row and column activity accounts for two vegetable industries – one in the north and one in the south of the country, or perhaps there are technology differences and one of the two vegetable industries uses irrigation and one does not. A second approach is to allocate the national-level results of a CGE analysis across production activities using a routine that is separate from the CGE model. The USAGE-ITC model,

Text Box 10.1. A Stochastic CGE Model: Caloric Intake in Bangladesh

"Commodity Price Volatility and Nutrition Vulnerability" (Verma and Hertel, 2009).

What is the research question? Agricultural production can be highly variable because of stochastic, or random, changes in weather. Production volatility in turn leads to volatility in food prices and food consumption. The authors examine how food price volatility leads to variability in caloric intake in Bangladesh. Could a special safeguard mechanism, which limits imports whenever their quantities surge, lead to increased average caloric intake or a reduction in its variability?
What is the CGE model innovation? The authors use a macro-micro model that links the GTAP CGE model with a micro-simulation model of the caloric intake of Bangladeshi households. Macroeconomic results from the CGE model are used as inputs into the micromodel of Bangladeshi households' food purchases. The authors define a stochastic shock to the total input productivity of grains and oilseeds production in the CGE model. This step creates baseline means and probability distributions for commodity prices and households' caloric intake. They validate their CGE model by testing that results from their stochastic productivity shock reproduces historical crop price volatility.
What is the experiment? The authors introduce their stochastic productivity shock with and without an offsetting special safeguard mechanism on imports.
What are the key findings? Differences among households in distributions of caloric intake, with and without import safeguards, are very small because Bangladesh does not import much of its food. The general lesson is that special safeguard policies raise food prices so they are likely to affect countries adversely, particularly their poor households.

for example, uses this "top down" approach. It includes an "add-in" that allocates endogenous national impacts from the CGE model across state-level industries and employment (see Text Box 3.2). For instance, perhaps the state of Michigan will receive 10% of the change in national U.S. consumer demand for good X. As in the macro-micro model of households, this approach does not allow feedback from changes in state-level production and employment back to the national CGE model.

Stochastic models are an innovative, frontier area of CGE modeling that is poised to make major contributions to the analysis of long-term climate change. Stochastic models stand in contrast to the deterministic CGE model that we have studied in this book. In a deterministic model, the solution value of every variable is uniquely determined by the equations, base data, parameter values, and shock. For example, an experiment may be a 10% change in wheat productivity, which results in a 10% change in the quantity of wheat production. Stochastic models account for the randomness that may be present in an economic environment. Perhaps year-to-year output of wheat is variable, and is expected to become increasingly variable because of climate change. A stochastic CGE model would describe the baseline output of wheat in terms of a mean value and probability distribution and the effects of a climate change shock as a change in the mean and distribution of wheat output. CGE modelers have taken different approaches to describing stochastic behavior in a CGE model. See for example, Block et al.'s (2006) study of droughts and floods in Ethiopia, summarized in Text Box 5.2, and contrast it with Verma and Hertel's (2009) study of the effects of world food price volatility on caloric consumption in Bangladesh, summarized in Text Box 10.1.

Dynamic CGE models essentially capture the notion that an economy's reaction to a shock, such as a new tax, changes its long-run growth trajectory. First, the models trace a baseline time path (usually a series of annual observations for specified time period) over which the supply and productivity of an economy's stock of capital and labor grows in the absence of a shock. A shock to the economy leads to changes in its growth trajectory by changing the timing and level of capital accumulation. Capital stock growth is altered when the experiment changes the rate of return to capital, which changes savings and investment behavior. Instead of static before and after snapshots, the results of a dynamic CGE model thus describe the difference between the baseline time path and the time path with the economic shock.[1]

Broadly speaking, there are two types of dynamic models. A recursive dynamic CGE model traces out a time path by sequentially solving a static model, one period at a time. First the model solves for one period after the shock, similar to a static model. Then all of the solution values are used as the variables' initial values for the next period and the model is re-solved, and so on. The capital stock grows over time because the change in savings that occurs in one period becomes an addition (minus depreciation) to the productive capital stock in the next time period. The modeler may also include time trends for labor force and productivity growth as the model is solved over the time path. Producers and consumers are assumed to be myopic. They minimize their costs or maximize their utility only for the current period, and they are assumed to believe that current economic conditions will prevail at all periods in the future.

Recursive dynamic CGE models are used by many governmental and international institutions to analyze important public policy problems. Prominent examples of these models are the World Bank's multi-country Linkage model (van der Mensbrugghe, 2005), the single-country MONASH model of

[1] See Devarajan and Go (1998) for an introduction to dynamic CGE models.

Australia (Dixon and Rimmer, 2002) and its descendant, the USAGE-ITC model of the United States (Koopman et al., 2002), and the World Bank's MAMS model (Gottschalk et al., 2009). Recursive dynamic models have also begun to assume an important role in the analysis of long-term global climate change. Recursive dynamic climate-focused models include CIM-EARTH (Elliott et al., 2010a), and the MIT-EPPA model (Paltsev et al., 2005).

The second type of dynamic CGE model is intertemporal. It assumes that producers and consumers have rational expectations, which means that they anticipate and take into account prices and income in all time periods as they make their current decisions. Producers minimize the present value of all of their costs over the full time period of the analysis, and consumers maximize their total utility over that period. Like the recursive model, an intertemporal CGE model describes two growth paths – with and without the economic shock. The models differ because the intertemporal type solves for prices and quantities in all time periods simultaneously. The time dimension adds many variables to the model. For example, the output of a single industry over a thirty-year time path equals thirty variables. Researchers therefore make a trade-off between the time dimension and the number of countries, industries, or consumer types in the model, so that these models usually offer very aggregated and stylized representations of an economy. As a result, this type of model is not typically maintained as a core analytical tool of institutions like the U.S. government. Nevertheless, intertemporal dynamic CGE models offer important insights and have provided the underpinnings for many influential studies of trade and tax policies (e.g., Goulder and Eichengreen, 1989; Jokisch and Kotlikoff, 2005; Rutherford and Tarr 2003; Diao, Somaru, and Roe, 2001).

Trade policy analysis continues to be one of the most important applications of CGE modeling. But as the global economy evolves, so too must the capability of CGE models to represent these new developments. Over the past decade, modelers have pushed out the frontiers of trade-focused CGE models in two areas. First, modelers recognize that regulations and other non-tariff barriers are not always adequately described by the *ad valorem* equivalents of tariffs and taxes that we studied in Chapter 9. Some NTMs are more accurately described as imposing fixed compliance costs rather than the variable costs depicted by an AVE. Like a tax, a variable compliance cost depends on production levels, such as an extra inoculation required for each exported chicken. A fixed compliance cost does not change based on production levels. Such an NTM may, for example, require an exporting firm to retrofit or build a new plant in order to meet the importer's sanitation requirements. Fixed costs are important because they can present "make-or-break" hurdles that make it infeasible for some firms to enter the export market.

The extension of CGE models to include fixed compliance costs in export markets follows the theoretical work developed by Melitz (2003). Instead of a single industry, as in the standard CGE model, "Melitz-type" models describe firms within each industry that are heterogeneous in their levels of productivity in serving the export market. When an NTM introduces a fixed compliance cost, the least productive firms find such costs to be insurmountable and will exit the export market. Conversely, when an NTM is eliminated, new firms may enter the export market. One of the contributions of this class of model is that it can describe changes in trade at the "extensive" margin – that is, trade may occur for firms or products in which trade had not previously taken place. A limitation of the standard CGE model is that it can describe only changes in trade at the "intensive" margin. That is, trade in a product may increase or decrease, but it will not take place if there is zero trade in the initial equilibrium. Thus the Melitz-type model helps solves the zero trade problem described in Text Box 2.2, and generally yields larger and more realistic trade gains following a trade policy reform. Petri and Plummer (2012), summarized in Text Box 10.2, developed an influential study of Asia-Pacific preferential trade initiatives using this Melitz-type of a CGE model.

A second frontier area in trade policy modeling describes the growing role of services in global trade, and the concomitant role of foreign direct investment (FDI) in driving this expansion. Christen et al. (2013) and Tarr (2013) provide informative overviews of the development of this literature. Until relatively recently, most CGE models described services as a non-traded good. Early efforts to account for services trade described it as a cross-border movement, similar to the shipment of goods, in which services such as call centers are provided by producers in one country to consumers in a foreign country. However, a characteristic of many services, particularly business services such as management consulting or organizational expertise, is that they must be provided on-site and in local proximity to the buyers. Trade in these kinds of services is therefore indirect in the sense that they are delivered by companies that have first engaged in FDI to set up local offices in the foreign country in order to provide such services to the local market.

There are two key assumptions about these firms, called foreign affiliates. One is that they have a different cost structure than do the local firms that produce similar services. In addition to using the same factor and intermediate inputs as the local firms, foreign affiliates also utilize an imported service input, which may be specialized technical or management expertise or advanced technology. The second assumption is that the skills and technologies embedded in the services produced by the affiliates make their product a productivity-enhancing intermediate input for local firms. Services

Text Box 10.2. A Melitz-type CGE Model with Fixed Export Costs due to an NTM

"The Trans-Pacific Partnership and Asia-Pacific Integration: Policy Implications" (Petri and Plummer, 2012).

What is the research question? There are multiple and overlapping efforts among subsets of Asian and Pacific countries to reduce or eliminate tariff and nontariff barriers on their intraregional trade and investment. What are the comparative effects of these alternative agreements on the economies of their members and of the rest of the world?
What is the model innovation? The authors utilize a "Melitz-type" CGE model that recognizes that firms are heterogeneous in their productivity in the production of exports. As a result, trade barriers that create fixed costs of entry into the export market are surmountable only for the most efficient firms. Trade liberalization can therefore result in trade expansion along the "extensive" margin in addition to growth in existing trade flows, along the "intensive" margin. The authors also account for the potential effects of the TPP in increasing international investment flows, and develop rich detail on non-tariff measures that impede regional trade.
What is the experiment? The authors simulate three approaches to trade liberalization: the Trans-Pacific Partnership, a regional Asian trade agreement, and a region-wide free-trade agreement.
What are the key findings? By 2025, the TPP track would yield global annual income gains of $294 billion, the Asian track would yield gains of $500 billion, and a region-wide agreement would result in income gains of $1.9 trillion. The assumption of fixed export costs and firm heterogeneity accounts for about 40% of the projected region-wide income gains.

liberalization scenarios describe the reduction of the tariff (or the AVEs of non-tariff barriers) on the services imports used by the foreign affiliates. This lowers the affiliates' cost of producing services and the price of their services in the local market. In turn, the increased use of these services by local producers leads to economy-wide productivity gains in the host country. Typically in these models, consumers also benefit from trade reforms because of the greater variety of services they can purchase. One of the main insights from this type of CGE model is that the predicted welfare gains from trade liberalization are substantially larger, and arguably more realistic, than traditional CGE-based analyses of trade liberalization that do not account for FDI, productivity gains, and consumers' love of variety. LaTorre (2016) provides an interesting application of this class of model that looks at the distributional impacts, by gender, of a trade reform in Tanzania that increases FDI and services trade (Text Box 10.3).

Text Box 10.3. A Model of FDI in Services with Gender Differences

"A CGE Analysis of the Impact of Foreign Direct Investment and Tariff Reform on Female and Male Workers in Tanzania," (Latorre, 2016)

What is the research question? Male and female workers in Tanzania have different skills, their employment is unequally distributed across industries, and female workers face a 40% earnings gap relative to males. Given these gender differences in Tanzania's labor market, how might a reduction in barriers to foreign direct investment affect its male and female workers differently?
What is the CGE innovation? LaTorre develops a CGE model that describes FDI in the business service sector and the endogenous productivity effects that stem from changes in intermediate input demand by local firms for the business services produced by foreign affiliates. She models barriers to FDI as *ad valorem* equivalent tariffs on the imported services that are used by the foreign affiliates as inputs into their production of business services. Her model also describes wages and employment by gender across four different skill categories of female and male workers in a 52-sector model of the Tanzanian economy.
What is the experiment? Latorre describes a reduction in the regulatory barriers to FDI as a 50% reduction in the AVE import tariff on the imports of business services used as intermediate inputs by foreign affiliate firms.
What are the key findings? Reforms lead to an increase in the number of foreign affiliates, a lower cost of their output of business services and an increase in the productivity of local firms that now use more of these services. These gains result in increased wages for all labor categories, even though foreign affiliates exhibit lower labor intensity in production than national firms. However, wage gains are higher for males than for females, and for skilled versus unskilled workers of both sexes, because the expanding foreign business services sector is relatively intensive in its use of male and skilled workers.

As we conclude our study of CGE models with this brief summary of its extended and frontier applications, it is a good idea to now think back to the simple bicycle model of Chapter 1 and to remind ourselves that, whether we use our simple model of supply and demand or advance to the frontiers of CGE modeling, we are always trying to distill a simplified representation of a complex world.

Model Exercises

Introduction

The objective of these 11 model exercises is to provide you with step-by-step guidance in building a model, designing experiments, identifying relevant results, and interpreting findings.

The exercises are intended to:

- Engage your interest by showing the breadth of real-world problems that can be analyzed using a CGE model.
- Illustrate how to use economic theory to make predictions about and to interpret model results.
- Demonstrate how the design of model experiments is grounded in economic theory and background research.
- Introduce a broad sampling of methodological tools, including how to change elasticities and model closure, decompose shocks into subtotals, develop baseline scenarios, and run sensitivity analyses of assumptions about elasticity parameter values and shock sizes.

The case studies are suitable for use with many types of CGE models. However, the detailed instructions provided in the model exercises are designed for use with the Global Trade Analysis Project (GTAP) CGE model. The model, developed by Thomas Hertel and colleagues at Purdue University, is documented in Hertel and Tsigas (1997). Its user-friendly, menu-driven interface, RunGTAP, was developed by Mark Horridge (2001) and is ideal for use by novice and advanced modelers alike.

Model exercises 1–3 show you how to create a small, three-sector, three-factor database for the United States and an aggregated, rest-of-world region from the GTAP global database (Table ME Introduction 1). The instructions also guide you in setting up, running, and learning about the GTAP CGE model. You should complete these three exercises sequentially before doing the subsequent case studies. You can also use the model developed

Table ME Introduction 1. *Skill Development in Model Exercises*

Exercise	Case Study	Economic Concepts	Modeling Skill
1. Set up the GTAP model and database			Download GTAP model, develop a database and SAM, run the model
2. Explore the GTAP model and database			Locate elements of model: sets, parameters, variables, equations, closure, and market-clearing constraints
3. Run the GTAP model			Define and run experiments, change elasticities and closure, read results, use GTAP utilities for welfare decomposition, and systematic sensitivity analysis
4. Soaring food prices and the U.S. economy	Trostle (2008), Sachs (2008), Cline (2007), Collier (2008)	Comparison of utility functions. Armington import demand, factor productivity	Change income and substitution demand elasticities, small country (fixed world price) closure
5. Food fight: Agricultural production subsidies	Samuelson (2005)	Production function, production subsidies	Use GTAP SUBTOTAL utility, change factor substitution elasticity
6. How immigration can raise wages	Borjas (2004), Ottaviano and Peri (2012)	Factors as substitutes and complements, factor endowment changes and factor prices	Change factor endowments and factor substitution elasticity
7. The Doha Development Agenda	Anderson and Martin (2005)	Input, output and export subsidies, import tariffs, welfare analysis	Use GTAP SUBTOTAL and welfare decomposition utilities, compare models
8. The marginal welfare burden of the U.S. tax system	Ballard, Shoven and Whalley (1985)	Taxation, tax burdens, welfare analysis	Use GTAP welfare decomposition and systematic sensitivity analysis utilities
9. Challenge exercise: Climate Change – The World in 2050	Nelson, et al., 2014.	Baseline scenario, closure, factor productivity, integrated assessment	Update model with macroeconomic projections
10. Challenge exercise: Successful Quitters: the Economic Effects of Growing Anti-Smoking Attitudes	Goel and Nelson, 2004.	Baseline scenario, utility functions, changes in consumer preferences, parameter uncertainty	Update model with macroeconomic projections, use GTAP systematic sensitivity analysis utility
11. Challenge exercise: Deep Integration in the T-TIP	Francois, et al. (2013)	Non-tariff measures, preferential trade agreements, trade creation, trade diversion	Update tariffs using Altertax, welfare decomposition

in these exercises to replicate the model results reported throughout the textbook chapters.

Model Exercises 4–11 provide case studies that complement and reinforce the concepts learned in the related chapters of the textbook. You can do all, or any one, of these exercises, and in any sequence. Model Exercises 9–11 present more challenging techniques for the advanced student. Model Exercises 4–11 are ideal for use as small, collaborative group projects. Each exercise poses questions about model results that can serve as a starting point for your exploration and study of your findings.

An important caveat about the model exercises is that they are only a teaching tool. Although the exercises introduce real-life problems and the practical modeling skills used in their analysis, the results from your small-dimensioned, toy CGE model should not be relied on as realistic.

Model Exercise 1: Set Up the GTAP Model and Database

Concepts: Download GTAP Model, Develop a Model Database, Create a SAM, Create Model Version, Run GTAP Model

In this exercise, you will learn how to (1) build a CGE model database and (2) set up and run a version of the GTAP model to use with your database.[1] In the first step, you will download the GTAP global database aggregator from the GTAP Web site. You will learn how to use the database aggregator to create a two-region, three-sector, and three-factor database that we use for examples throughout the book and in the model exercises. The two regions are the United States (USA) and the rest of the world (ROW); the three sectors are agriculture, manufacturing, and services; and the three factors are land, labor, and capital. We use the GTAP version 8.1 database, released in February 2013. It describes the global economy in 2007. You may carry out the model exercises with other versions of the GTAP database, but model results will differ from those reported in the answer key.

In the second step, you will download the RunGTAP model and learn how to create a "version" of the model to run with your 3×3 database. At the end of this exercise, your CGE model and database will be ready to use for analysis or to replicate modeling examples in Chapters 1–8.

A. Create a Folder on Your Computer for Your Project

Create a folder on your computer in which you will save your database and all of the other files that you will create for your research project. Name the directory "MyLastName" or something else that is easy to remember.

B. Download the Database Aggregator and Create a Model Database

The GTAP model can be used interchangeably with any aggregation of the GTAP database. You will use the GTAP version 8.1 database, with a 2007 base year, to create a three-sector, three-factor aggregation that describes the United States and an aggregated rest-of-world region. We refer to it as the U.S. 3×3 database throughout this book. You can follow these same steps to create a database for your individual research project. Instead of the United States and rest of world, you may choose to study different aggregations of countries, industries, and factors of production. Without a GTAP database license, you are restricted to three countries and three sectors. Even with a license, we encourage you to limit yourself to no more

[1] For students with some experience in GEMPACK, Pearson and Horridge (2003) provide a detailed introduction to the GEMPACK software and its use in the GTAP model. Also, see Horridge (2015a, 2015b) on use of the GTAP aggregation utility.

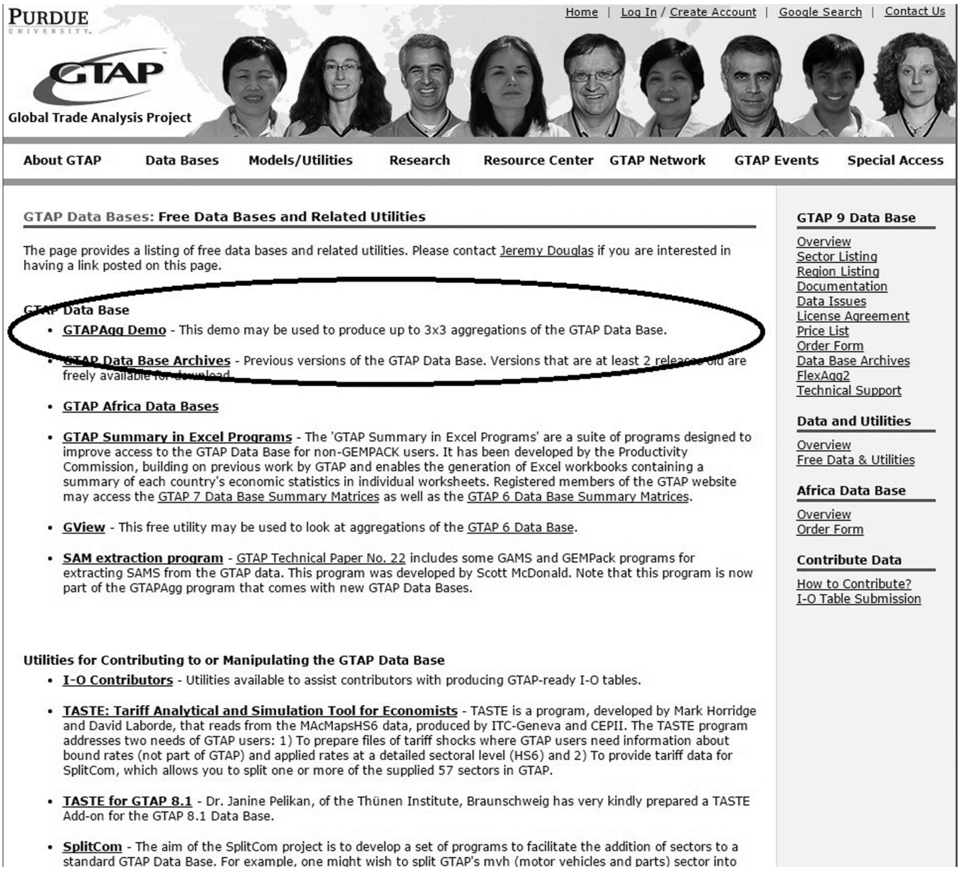


Figure ME 1.1. Download GTAP-Agg demo.

than ten industries and four factors of production. Otherwise, it becomes difficult to distill key results and major findings, especially as a beginning modeler.

The following instructions are consistent with the GTAP Web site as of December 2016. You may need to adapt these instructions if the GTAP Web site changes over time.

1. Go to www.GTAP.org
2. Become a member of GTAP. Select "My Account" from the top menu bar and register as a new member. If you are a member already, log in.
3. From the main menu:
   - Select Databases
   - Select Free Databases from the drop-down menu
   - Select GTAP-Agg Demo (see Figure ME 1.1).
   - Click on GTAPAgg8.1 Demo, from the "Attachments" section at the bottom of the page.
   - Download the GTAP-Agg demo file and save it into your download directory.

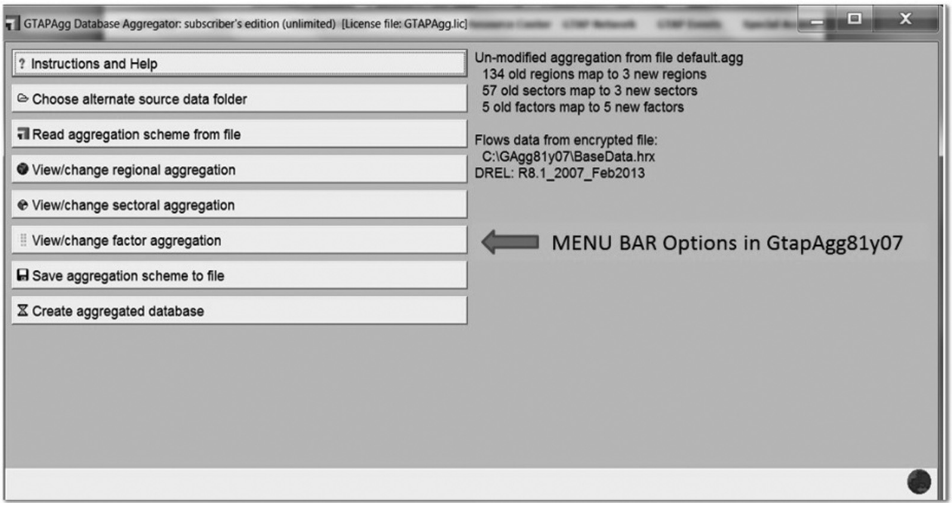


Figure ME 1.2. GTAPAgg7 menu bar options.

4. Open the contents of the zipped file and double-click on the file Setup.exe. The installation program will prompt you to install the data GTAPAgg program to your hard disk in directory “C:/GTAPAgg81y07.” You may instead specify any drive in which you prefer to install the program. (You may need to adapt these installation instructions to the operating system and program installation procedures on your computer).
5. Open the GTAPAgg data aggregation program. Either click on the GTAPAgg81y07 icon on the desktop or go to “Start” and select “All Programs,” then select “GTAPAgg81y07.” The GTAPAgg program will open and display the menu bar options shown in Figure ME 1.2.
6. Define the country/region aggregation:
   - From the menu bar options, select “View/change regional aggregation.”
   - In the table at the bottom of the page (shown in Figure ME 1.3), define two regions by right-clicking on rows and deleting all but two.
   - In the left column of the table, “New region code,” relabel the rows “USA” and “ROW.”
   - In the right column of the table, “New region description,” enter “United States” and “Rest of World” to match the new region codes.
7. Map all countries into a two-region aggregation:
   - Go the mapping table in the upper right quadrant of the page.
   - Click on the center column (New region) of the first row (Australia), and pull down the mapping menu, which should list “unmapped,” “USA,” and “ROW.”
   - Map all countries in the mapping table, except the United States, to ROW. Then map the United States to USA. When you are finished, only “USA” should occupy the “comprising” column in the table at the bottom of the page for the newly defined “USA” region. All other regions should be mapped to “ROW.”
   - Click on OK (this saves your regional aggregation).

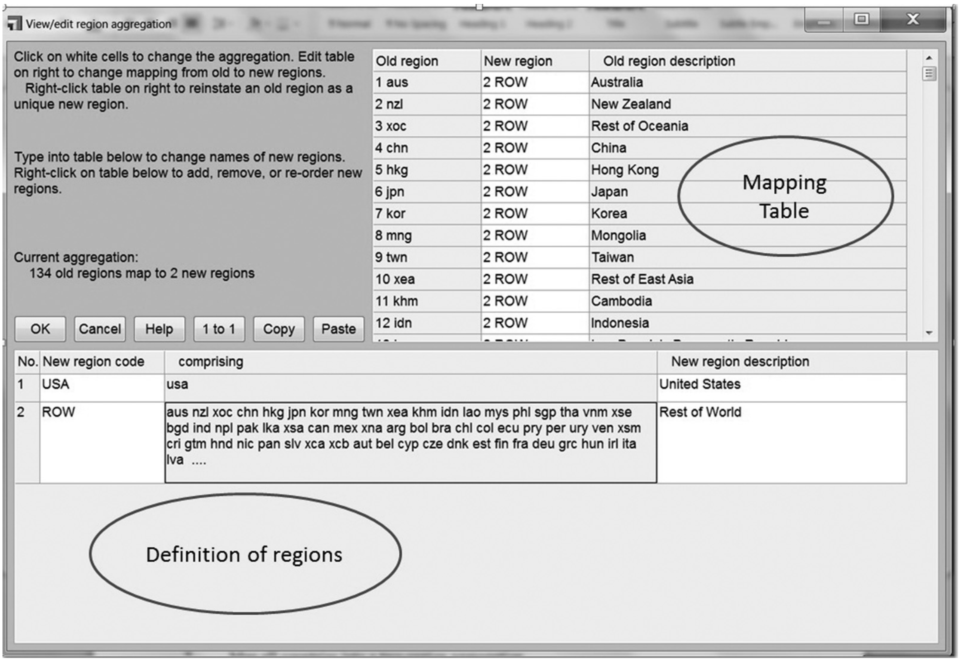


Figure ME 1.3. Mapping regions in GTAPAgg7.

8. Define the sector aggregation:
   - From the menu bar, select "View/change sectoral aggregation." This opens a mapping page similar to that used to create the regional aggregation (shown in Figure ME 1.4).
   - In the table at the bottom of the page, right-click to remove all but three sector rows.
   - In the left column of the table, "New sector code," relabel the rows "AGR," "MFG," and "SER"
   - In the right column, "New sector descriptions," describe these sectors as Agriculture, Forestry, Fishery; Manufactures; and Services.
9. Map sectors to a three-sector aggregation:
   - In the mapping table in the upper right quadrant of the page, click on the center column (New sector) of the first row (paddy rice) and pull down the mapping menu, which should list "unmapped," "AGR," "MFG," and "SER."
   - Map sectors 1–14 into AGR; sectors 15–42 into MFG; sectors 43–57 into SER. (These may already be the default sector aggregations in GTAPAgg81y07.)
   - Click on OK (this saves your sector definitions).
10. Define the factor aggregation:
    - From the menu bar, select "View/change factor aggregation." This opens a mapping page similar to that used to create the regional aggregation (shown in Figure ME 1.5).
    - In the table at the bottom of the page, right-click to remove all but three factor rows.
    - In the left column, type "LAND," "LABOR," and "CAPITAL," putting one factor in each row.

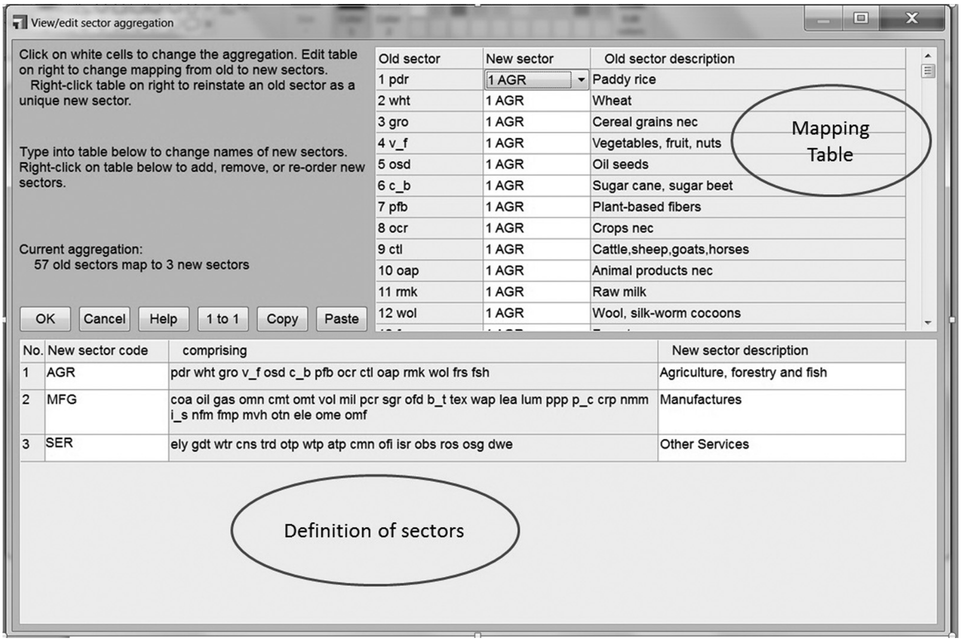


Figure ME 1.4. Mapping sectors in GTAPAgg7.

11. Map factors into three-factor aggregation:
    - In the mapping table in the upper right quadrant, click on the center column, “New factor” and pull down the mapping menu, which should list “unmapped,” “LAND,” “LABOR,” and “CAPITAL.”

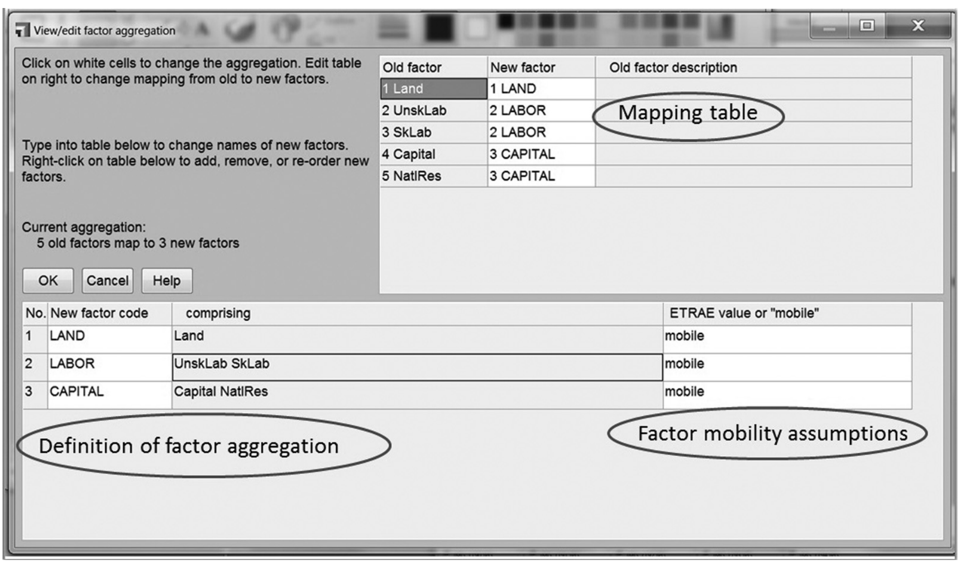


Figure ME 1.5. Mapping factors in GTAPAgg7.

- Map: land to LAND; skilled and unskilled labor to LABOR; and capital and natural resources to CAPITAL.

12. Define factor mobility assumptions:
    - The column labeled "ETRAE or mobile" describes the model's factor mobility assumptions. We study factor mobility assumptions in detail in Chapter 6. For now, simply change all factor mobility assumptions in this column to "mobile."
    - Click on OK (this saves your factor definitions).
13. Save your data aggregation file:
    - From the menu bar, select "Save aggregation scheme to file." (GTAP provides a default name, "gtp3_2," which you can change to something more descriptive, like US3×3v8.
    - Save this aggregation file in the folder that you created for your research project.
14. Create the aggregated database:
    - From the menu bar, select "Create aggregated database." This creates a zip file with the aggregated database. Give it the same name as your aggregation scheme (e.g., US3×3v8.zip), and save it in your project folder.
    - Your database is now saved in Header Array (HAR) files that are ready to use in your CGE model.
15. Create a Social Accounting Matrix (SAM) in Excel:
    - From the menu bar, select "View Output files."
    - Select GTAPSAM.har (this opens a list of HAR, or header array, files).
    - Click on ASAM – Aggregated Social Accounting Matrix. This will open a file in ViewHar, the software that is used to view HAR files.
16. Display the U.S. SAM:

    A HAR file often contains data of more than two dimensions. To display the data of interest to you, select the dimensions, or elements, of the database in the upper right corner of the file (shown in Figure ME 1.6). To display all SAM accounts for the United States, select these dimensions:
    ALL ASAMAC, ALL ASAMAC, USA

17. Export the U.S. SAM database to Excel:
    - To improve readability, reduce the number of decimal points in the SAM from 3 to 0 by clicking on the "3" in the upper left-side toggles of the ViewHar page (shown in Figure ME 1.6). A drop-down menu displays decimal display options – select "0".
    - From the upper left-side menu bar on the ViewHar page, select "Export"
    - Select "Copy Screen to Clipboard" from drop-down menu
    - Open Excel
    - Paste SAM into an Excel file and save it as US3×3v8.xls.
    - Verify that your SAM's column sums match those displayed in Figure ME 1.6. If they do not, check the elements that you have selected for display in ViewHar. If these are correct, then reopen your aggregation file and check your definitions of regions, sectors, and factors, for errors. Correct them and recreate the aggregated database.

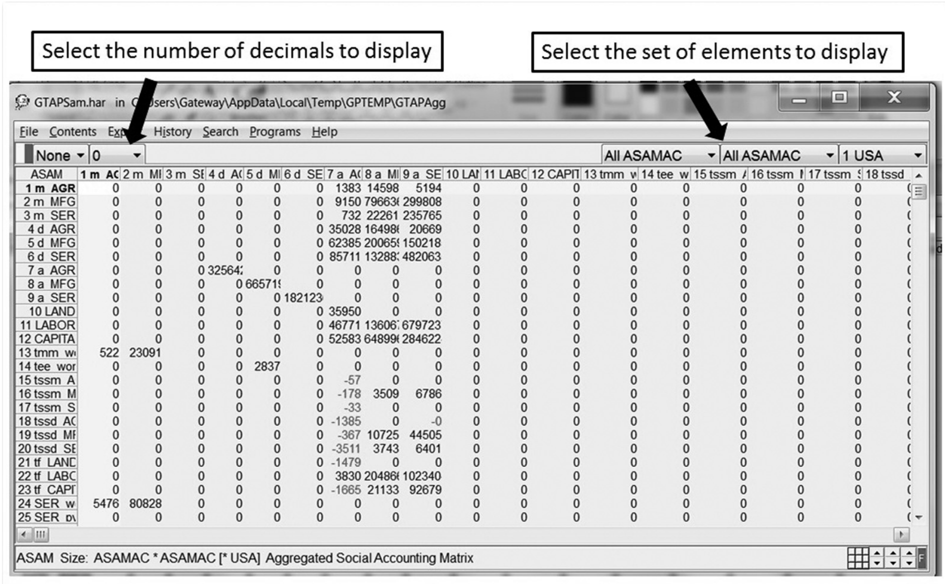


Figure ME 1.6. The U.S. Social Accounting Matrix in ViewHar.

C. Download the GTAP Model

These directions for downloading, unzipping, and installing the GTAP model are quite general. Your computer and browser may present a slightly different set of choices for how to do this. The important thing is that you download the model, unzip it, locate the SETUP.exe file, and run the installation program. The installation will create a directory on your hard drive, RunGTAP5, in which the model will be placed.

1. Go to www.GTAP.org
2. From the main menu bar:
   - Select Models/Utilities
   - Select RunGTAP, from the Models/Utilities drop-down menu
   - Select Download RunGTAP, from the RunGTAP downloads section.
3. Download the file and select "Unzip and Install." Then select "Set-up," and the program will prompt you to install the program to your hard disk. The default directory is C:/RunGTAP, but you may choose to install it in a different directory. (Another option is to download and save the file to your temp directory and install it from there, first by clicking on the zipped RunGTAP file and then by clicking on the "set-up" computer icon inside it.)

D. Create a Version of the GTAP Model for the US3×3 Database

The GTAP model is expressed in general functional notation so that it can be used with any aggregation of the GTAP database. In this exercise, you

Figure ME 1.7. GTAP model.

will create a "version" of the GTAP model that uses the U.S. 3×3 database. The model version will be called "US3×3." You can follow these same steps to create a version of the GTAP model that works with any aggregation of a GTAP database.

1. Open the RunGTAP model by clicking on the Windows icon for RunGTAP or open it from your Start menu. The title page includes a menu bar at the top and page tabs below the menu bar (Figure ME 1.7). The first time you open it, there may be a warning that an SLI file is missing or obsolete. If so, select "OK."
2. Create a U.S. 3×3v8 version of your model. In RunGTAP:
   - Select "Version" from the menu bar
   - Select "New" from the drop-down menu
   - Next
   - Select "New Aggregation" and NAME it: US3×3
   - Next
   - Click on "Locate the Zip archive" (the bottom "locate button")
   - Select the US3×3v8 zip file in the folder that you created for your research project, and click on "Open"
   - Next
   - Finish
   - OK

There is now a folder with the name of your version (i.e., US3×3) saved in the RunGTAP5 directory. GTAP software automatically runs a consistency check and a numeraire experiment using your new database. If this completes successfully, your U.S. 3×3 model is ready to use for experiments.

3. Describe the version of your model:
   - From the menu bar in the RunGTAP model, select "Tools"
   - Select "Options"
   - Check the "Developer mode" box
   - OK
   - Select Version from the page tabs (not from the menu bar above)
   - Delete all the text on this page and write your own brief description of your US3×3 model; for example, "US3×3 model has two regions (U.S. and Rest of World), three factors (Land, Labor, and Capital), and three sectors (Agriculture, Manufacturing, and Services).
   - From the menu bar, select Developer
   - Select "Save Version.txt" from the drop-down menu
   - OK
   - From the menu bar, select Tools
   - From the drop-down menu, select "Options"
   - Uncheck the "Developer mode" box
   - Select "OK"

When you open the GTAP model, it always opens the last version that you worked on. If you want to work with a different version, or if you want to change versions as you are working, select "Version" from the menu bar (at the top of the page), and you will find a list of model versions, including the U.S. 3×3 and any other versions that you have created. Select the version that you want to open.

E. Change to Uncondensed GTAP Model

In this course, we will use the "uncondensed" GTAP model, which includes more tax and productivity parameters than the default, condensed version. You may switch to an uncondensed version for all of your GTAP model applications, or (recommended) switch to the uncondensed GTAP model only for the US3×3 model version:

1. Change to the uncondensed GTAP model for your US3×3 model version:
   - Select "Version" from the menu bar
   - Select "Modules" from the drop-down menu
   - In the Main model row, and the Version-Specific settings columns, click on the blank cell in the center (Tab file) column
   - Select "Stored in Main Folder"
   - From the drop-down box, select GTAPU.TAB
   - Click on OK
   - OK
   - OK
2. Run a test simulation:
   - Select "Tools" from the menu bar
   - Run test simulation from the drop-down menu

- Continue to select OK if there are bad closure warnings, even if there are several.

The GTAP program will now use the uncondensed GTAP model for your US3×3 model version.

Model Exercise 2: Explore the GTAP Model and Database

Concepts: Locate Elements Of Model – Sets, Parameters, Variables, Equations, Closure, and Market-Clearing Constraints

The objective of this model exercise is to give you an orientation to the main components of the CGE model and its database. You will learn how to open and search the CGE model's program code, and you will locate and identify your model's sets, parameters, variables, closure, and market-clearing constraints.

A. Open the Version of the GTAP Model with U.S. 3×3 Database

1. Open "RunGTAP"
2. On the menu bar, choose "Version"
   - Change
   - Select US3×3
   - OK

B. Explore the Sets in the Database

1. Open the sets file
   - On the menu bar, select "View"
   - From the drop-down menu, select "Sets"
     This opens a HAR file that lists all sets in the model (Figure ME 2.1).
2. Identify the regions in the model database
   - Double-click on Set REG (in row 2).
   - Write the elements of REG (regions in model):

     ____

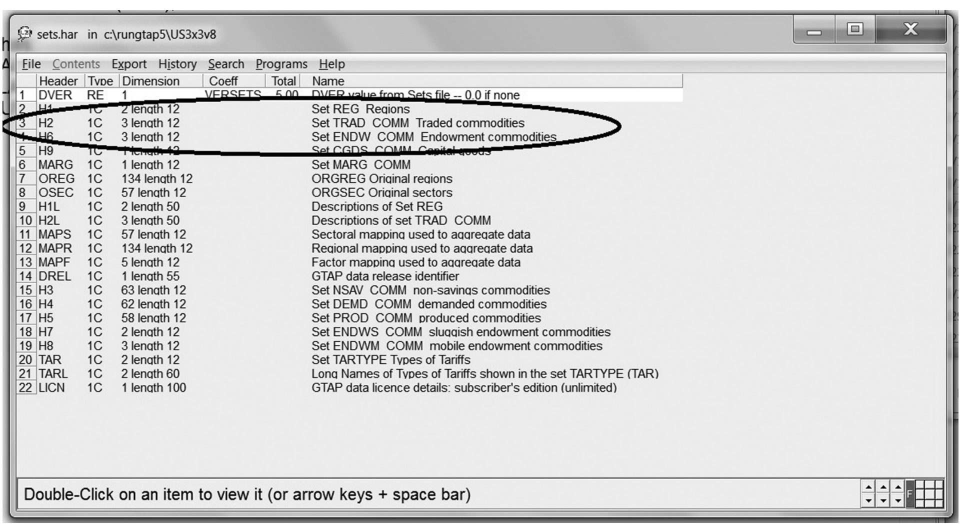


Figure ME 2.1. View set elements.

3. Identify the sectors in the model (they are called traded commodities)
   - Click anywhere in the matrix to return to the previous menu
   - Double-click on Set TRADE_COMM (in row 3)
   - Write the elements of TRAD_COMM (traded commodities):

4. Identify the factors in the model
   - Click anywhere in the matrix to return to the previous menu.
   - Double-click on Set ENDW_COMM (in row 4)
   - Write the elements of ENDW_COMM (factors of production):

   - Close the sets.har file by clinking on the red x in the upper right corner of the HAR file

C. Explore Table Dimensions of a HAR File

Tables have only two dimensions, rows and columns, yet many variables in the CGE model have more than two dimensions. For example, in the GTAP model, parameter rTMS(TRAD_COMM, r, s) is the import tariff rate on traded goods imported by country s from country r. The parameter has three dimensions: It is defined for the set of traded goods (TRAD_COMM); the set of source countries, r*;* and the set of destination countries, s. To explore variables like this one, you will need to learn how to view variables and parameters of three or more dimensions in a two-dimensional table.

Data used in the GTAP model are contained in header array (HAR) files. You select which dimensions to display in the HAR file by selecting set elements from the drop-down boxes in the upper right corner of the file (Figure ME 2.2). There is one drop-down box for each dimension of the

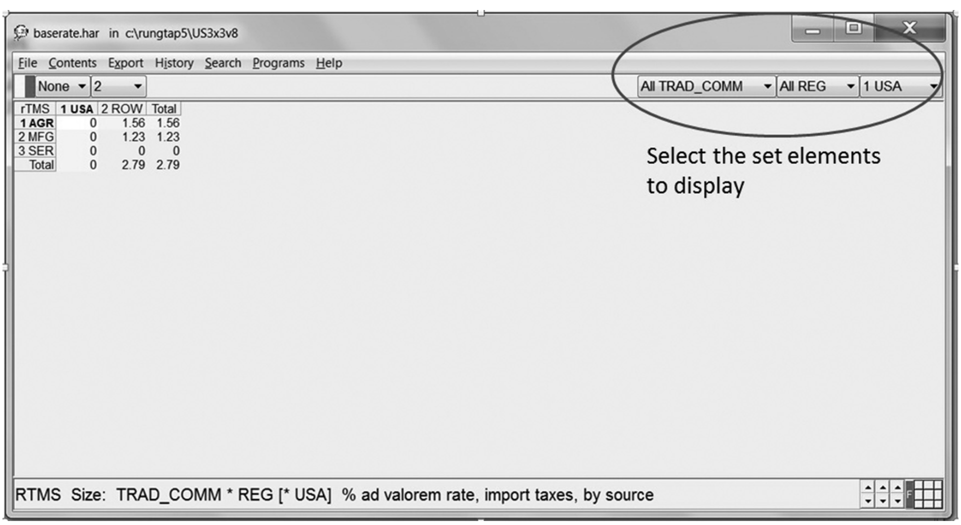


Figure ME 2.2. Select the set elements to display.

variable. In the case of import tariffs, for example, there are three drop-down boxes: TRADE_COMM, countries *r*, and countries *s*. (If the variable has only two dimensions, only two drop-down boxes appear in the upper right corner of the file.) Note the set name convention in the GTAP model – country *r*, usually the first country in a variable name, is always the exporter, or source country, of a traded good; and country *s*, usually the second country in the variable name, is always the importing, or destination, country of a traded good.

In the following steps we show how to view in a table the U.S. import tariff rates on each commodity from each of its trade partners. In this case we want to display data for all traded goods (TRAD_COMM) and all source countries, *r*. We will display data for only one importing country, *s*, which is the United States.

In RunGTAP:

- Select "View" from the menu bar
- Select "Base data" from the drop-down menu
- Select "Tax rates" from the drop-down menu
- Double-click on "rTMS", which reports import tariff rates
- In the upper right corner of the HAR file, the left side box is ALL TRAD_COMM. Its drop-down box displays all elements of this set: AGR, MFG, and SER. Select "All TRAD_Comm." This selection means that data for every traded commodity will be reported in the table.
- In the upper right corner of the HAR file, the center box is ALL_REG. Its drop-down box displays all elements of set *r*, the source country for imports. In our model, the set *r* includes the USA and ROW. Select "ALL_REG." This selection means that all source regions will be reported in the table.
- In the upper right corner of the HAR file, the right side box is Sum REG. Its drop-down box displays all elements of set *s*, the destination country for imports. Select "USA." This selection means that data for only one element of set *s* will be displayed.
- Experiment with selecting other elements of set *s*, in the right-hand drop-down menu. What happens if you select "ALL_REG"?
- Close the base rate HAR file by clicking on the X in the big red box in the upper right corner.

D. Explore the Elasticity Parameters

In RunGTAP:

- Select "View" from the menu bar.
- Select "Parameters" from the drop-down menu. This HAR file contains all of the elasticity parameters used in model equations.
- Select INCPAR (row 3).
- What is the INCPAR parameter for U.S. services?

Table ME 2.1. *Elasticity Parameters for U.S. Agriculture*

Elasticity	Value
Supply parameters	
Factor substitution (ESUBVA)	0.25
Intermediate input substitution (ESUBT)	
Demand parameters	
Consumer income (INCPAR)	
Consumer substitution (SUBPAR)	
Import substitution (imports v. domestic good) (ESUBD)	
Import substitution (among trade partners) (ESUBM)	

- INCPAR("USA", "SER") = __________
- Double-click anywhere in the file to return to the list of parameters.
- Report the elasticities for U.S. agriculture in Table ME 2.1.
- Close the default.prm file by clicking on the X in the big red box in the upper right corner.

E. Explore the Tax Rate Parameters

In RunGTAP:

- Select "View" from the menu bar.
- Select "Base data" from the drop-down menu.
- Select "Tax rates" from the drop-down menu. This HAR file reports all of the tax rates in the GTAP model.
- Double-click on the rTO (first row) to display the output (or income) tax rate.
- In the Table ME 2.2, report the production tax rate for U.S. agriculture (a negative rate denotes a subsidy).
- Write the names of all of the other taxes in the GTAP model in Table ME 2.2.

Table ME 2.2. *Tax Rates for U.S. Agriculture*

Tax rate	Name	Value
rTO	% ad valorem output (or income) subsidy in region *r*	–0.24
rTF		
rTPD		
rTPI		
rTGD		
rTGI		
rTFD		
rTFI		
rTXS		
rTMS		

- For each tax, report the tax rates for U.S. agriculture in Table ME 2.2. Be careful to check the dimensions in the upper right corner of the HAR files. The taxes on factor and intermediate inputs, and export and import taxes, are three-dimensional parameters. Report the factor tax rate on land used in U.S. agricultural production, the tax rate on U.S. firms' use of agricultural inputs in agricultural production, the export tax on agricultural goods shipped from the United States to ROW and the import tariff on agricultural goods shipped from ROW to the United States.
- Close the base rates HAR file by clicking on the big x in the red box in the upper right corner of the file.

F. Explore Model Closure

Model closure defines which variables are endogenous and which variables are exogenous, or fixed.

1. Find the Variable Names and Definitions in the GTAP Model

In RunGTAP:

- Select "View" from the menu bar
- Select "Variables and subsets" from the drop-down menu
- Select "Variables" from the folder tabs in the information file.

Write the definition of the following variables:

pm ____
pop ____
qfe ____
qiw ____

- Close the information HAR file by clicking on the red x in the upper rifht corner of the file.

2. Find the Model Closure Statement and Identify the Endogenous and Exogenous Variables

The GTAP model assumes that all model variables are endogenous unless they are explicitly defined to be exogenous. To see which variables are defined as exogenous:

- Select "Closure" from the page tabs.

Which of the variables listed in F.1 are exogenous? Which are endogenous?

Exogenous: ____
Endogenous: ____

G. Explore the Equations in the GTAP Model

You will become more familiar with the equations of the GTAP model as you gain experience in running the model and analyzing your results. For now, just open the GTAP model's underlying program code and find the road map that describes how equations are organized into blocks of model code:

In RunGTAP, select:

- "View" from the menu bar
- "Tab files" from the drop-down menu
- "Main model" (this command displays the programming code of the main GTAP model).

Search for the term "Overview of the GTAP.TAB Structure," by selecting:

- Search
- Find
- Enter the search term in the search box.

This section of the model describes the organization of the modeling code in the GTAP model into preliminaries, modules with economic equations, and appendices.

H. Explore Market-Clearing Constraints

Still in the GTAP.tab file, search for an identity equation that is an example of a market-clearing constraint that ensures that the model's results describe an economic equilibrium in supply and demand. In the search box, enter the term:

"MKTCLDOM"

This equation imposes the constraint that, in each country, the total domestically produced supply of each good is equal to the sum of demand for that good by firms, households, and government.

Model Exercise 3: Run the GTAP Model

Concepts: Define and Run Experiments, Change Elasticity Parameters and Model Closure, Read Model Results, Use GTAP Utilities for Welfare Decomposition and Systematic Sensitivity Analysis

In this exercise, you will learn to define and run a model experiment (called a "shock") and to search for and report model results. You will learn how to change an elasticity parameter, change a model closure, and export and compare results. This exercise also shows you how to use GTAP utilities for welfare decomposition and for a systematic sensitivity analysis with respect to elasticity parameters. Model Exercise 3 is designed to serve as a reference that you can turn back to for basic directions as you carry out Exercises 4–11. In this exercise, we focus only on the mechanics of using and controlling the GTAP model; we study the economic behavior in the model in Exercises 4–11.

A. Open GTAP Model with U.S. 3×3 Database

This step opens the "version" of the GTAP model that uses the U.S. 3×3 database. You created this version of the model in Model Exercise 1.

1. Open RunGTAP
2. On the upper menu bar, choose Version
   - Select "Change" from the drop-down menu. This opens a list of model versions.
   - Select US3×3
   - OK (this changes the database, or version, used in the GTAP model).

B. Prepare Your Model to Define and Run an Experiment

The following housekeeping steps may not always be necessary, but, like a pilot's preflight checklist, it is a good practice to follow them before defining or running any model shock.

1. Prepare your model to define an experiment – check closure
   - Select the Closure page tab

Check that no closure changes are lingering there. The closure should end with "Rest Endogenous." If not, erase all text below that line.

2. Prepare your model to define an experiment – check shocks
   - Select Shocks page tab
   - Clear shock list

This check ensures that there are no shocks lingering in your experiment file other than those you want to introduce.

3. Check the elasticity parameter file
   - Select Solve page tab
   - Check that the parameter file named in the upper right corner is your preferred file (in this exercise, let it remain as the default parameter file).
4. Check model solution method
   - Select Solve page tab
   - Solution Method (in the upper right corner of the page): select "Change"
   - Choose "Gragg" solution method. (Your choice of solution method may vary; this is the method we use for this exercise. It divides the shock into smaller shocks which the model solves sequentially.)
   - OK (this selects the new solution method)

C. Define a Model Experiment Using the "Shocks" Page

Experiments are defined on the "Shocks" page (see Figure ME 3.1). In this exercise, you will introduce a 10% output subsidy to U.S. manufacturing. The GTAP model defines an output tax/subsidy (*to*) and export subsidy (*txs*) as a positive number when they are a subsidy and a negative if they are a tax; other taxes in the GTAP model define positive values as a tax and negative values as a subsidy. Table ME 3.1 provides a helpful guide for correctly defining a

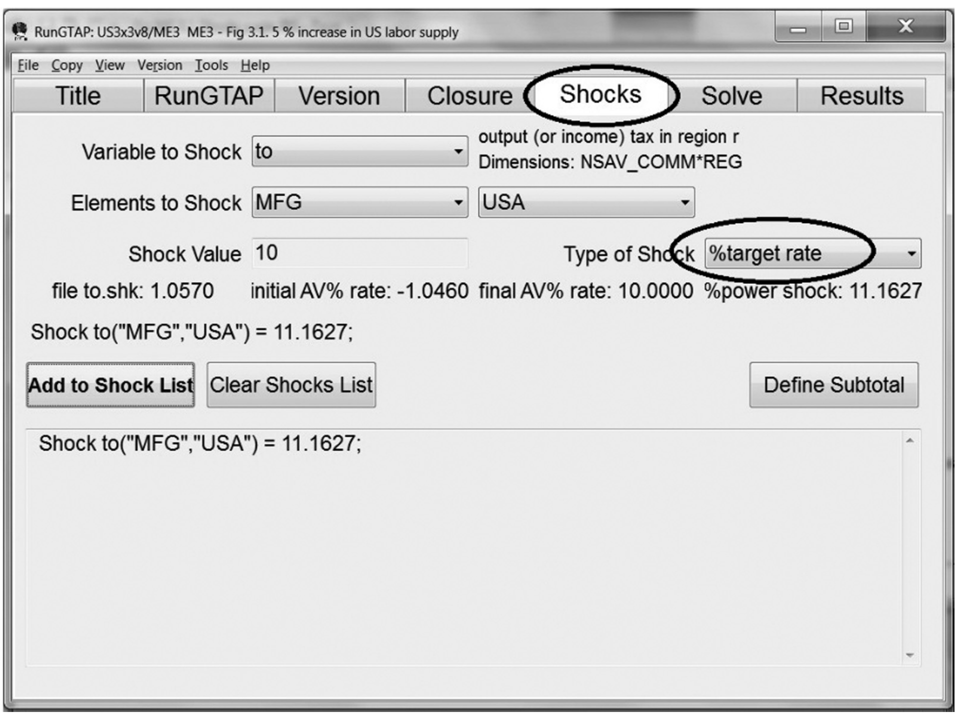


Figure ME 3.1. Shocks page.

Table ME 3.1. *Shocks Page in GTAP CGE Model – Setting Up a Tax Experiments*

Tax/ subsidy	Definition	Effect of cut in absolute value of tax if: Initial AV rate > 0	Effect of cut in absolute value of tax if: Initial AV rate < 0
to_r	Output or income subsidy in region r	Output subsidy falls	Output tax falls
$tf_{f,j,r}$	Tax on primary factor f in region r	Factor use tax falls	Factor use subsidy falls
$tpd_{i,r}$	Sales tax on private domestic consumption	Consumption tax falls	Consumption subsidy falls
$tpm_{i,r}$	Sales tax on private import consumption	Consumption tax falls	Consumption subsidy falls
$tgd_{i,r}$	Sales tax on government domestic consumption	Consumption tax falls	Consumption subsidy falls
$tgm_{i,r}$	Sales tax on government import consumption	Consumption tax falls	Consumption subsidy falls
$tfd_{i,j,r}$	Sales tax on firms' domestic input use	Use tax falls	Use subsidy falls
$tfm_{i,j,r}$	Sales tax on firms' imported input use	Use tax falls	Use subsidy falls
$txs_{i,r,s}$	Export subsidy	Export subsidy falls	Export tax falls
$tms_{i,r,s}$	Import tariff	Import tax falls	Import subsidy falls

GTAP model experiment that imposes a percent change on an initial tax or subsidy rate.

1. Select the "Shocks" page tab
   - Select from the "Variable to Shock" drop-down menu: *to*
   - Select from the "Elements to Shock" drop-down menu: MFG
   - Select from the Region drop-down menu: USA
   - For "Shock Value" enter: 10 (positive value is a subsidy, negative is a tax)
   - Select from the "Type of Shock" drop-down menu: % target rate
   - Click on "Add to shock list."
   - Verify that the shock to the U.S. production tax is the only shock in the shocks list
2. What is the initial *ad valorem* (AV) tax rate of "to" in U.S. manufacturing? __________
3. Is the initial rate of "to" a subsidy or a tax? __________________

D. Save a Model Experiment and Solve the Model

Select the "Solve" page tab:

1. Save the experiment file
   - Check solution method. It should be Gragg 2-4-6. If it is not, click on "Change," select Gragg, and then click on "OK."

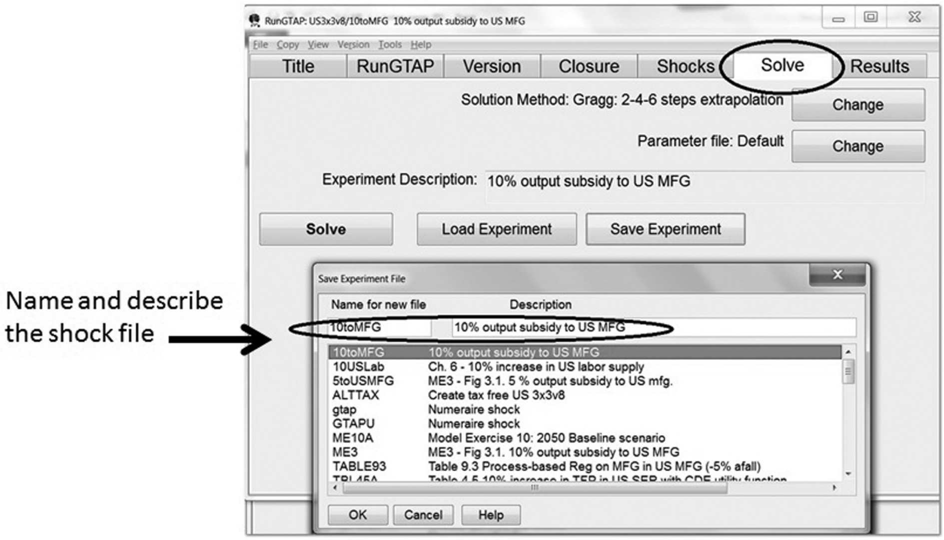


Figure ME 3.2. Solve page.

- Check parameter file. It should be "Default." If it is not, click on "Change," select "Default" from the box, and click on "OK."
- Click on "Save experiment"
- Name the experiment: 10toMFG (see Figure ME 3.2)
- Description: "10% output subsidy to U.S. MFG"
- OK (this saves the experiment file).

2. Solve the model
   - Still on the Solve page, click on the "Solve" button
   - OK (this closes the accuracy summary report box)
   - OK (this closes a solution information box).
3. Verify that your tax shock was what you think it is. Select:
   - "View" from the menu bar
   - "Updated data" from the drop-down menu
   - Updated tax rates
   - Click on the first row, rTO, to view the rTO matrix and then check the entry for row "MFG" and column "USA."
   - Confirm that rTO for USA MFG is now approximately 10.0. (Note that in this display, a negative value is a tax and a positive value is a subsidy.)
   - Close the file by clicking on the X in the big red box in the upper right corner.

E. Find and Report Experiment Results

Model results for most variables in the model are reported on the Result page, which is opened by clicking on the Results page tab (Figure ME 3.3). GTAP's naming convention is to use lowercase letters to denote a variable reported as a percentage change from base values, and uppercase letters to denote a variable reported in levels. For example, variables in lowercase,

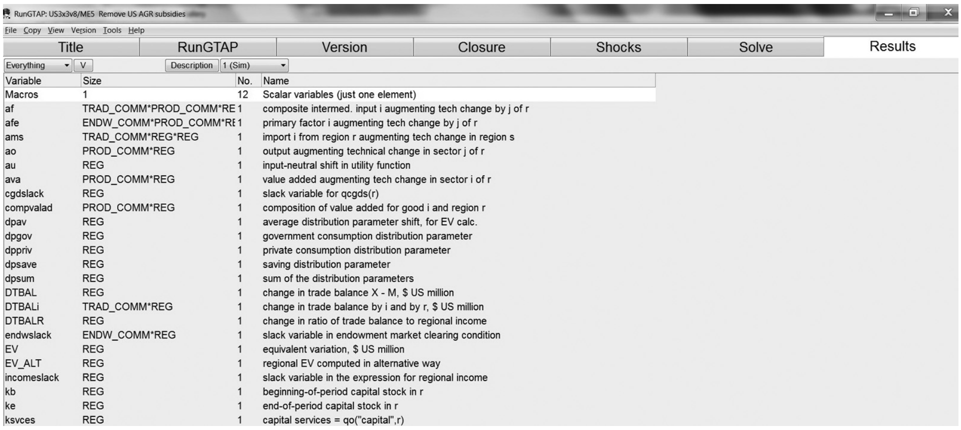


Figure ME 3.3. Results page.

such as *ps* or *pm*, are the percentage changes in the producer supply price and market price of a good, respectively. The variable DTBAL is the change in a country's trade balance, reported in $U.S. millions.

1. Find a variable result on the "Results" page
   - Select the Results page tab. (Variables are listed in alphabetical order.)
   - Write the definition of the variable *qo("MFG", "USA")* in Table 3.2
   - Double-click on variable *qo*
   - Report the result for variable *qo("MFG", "USA")* in the United States in the "base results" column of Table 3.2
   - Write the definition of the variable *qo("MFG", "ROW")* in Table 3.2
   - Report the result for manufacturing output in ROW in the "Base results" column of Table 3.2
   - Double-click on data anywhere in the table to return to the variable list.
2. Display results of variables with three dimensions using data filter

Tables are two-dimensional displays of data, but some variables have more than two dimensions. For example, variable *qfe(i,j,r)* has three dimensions: the quantity of factor *i* used in industry *j* in country *r*. To display results for variable *qfe*, use the data filter in the upper left corner of the results page to select the dimensions to control and the dimensions to display (see Figure ME 3.4). In the following example, you will control dimension r by selecting "USA," so that the variable *qfe(i,j,"USA")* is displayed in a table with a dimension of *i* by *j*.

- Locate variable *qfe* in the list of results and write its definition in Table ME 3.2
- Double-click on variable *qfe* – you'll get an error – "Sorry, you cannot view a 3-D matrix."
- From the drop-down menu on the upper left side, which says "Everything," choose "USA" – this controls set *r* so that sets *i* and *j* can be displayed

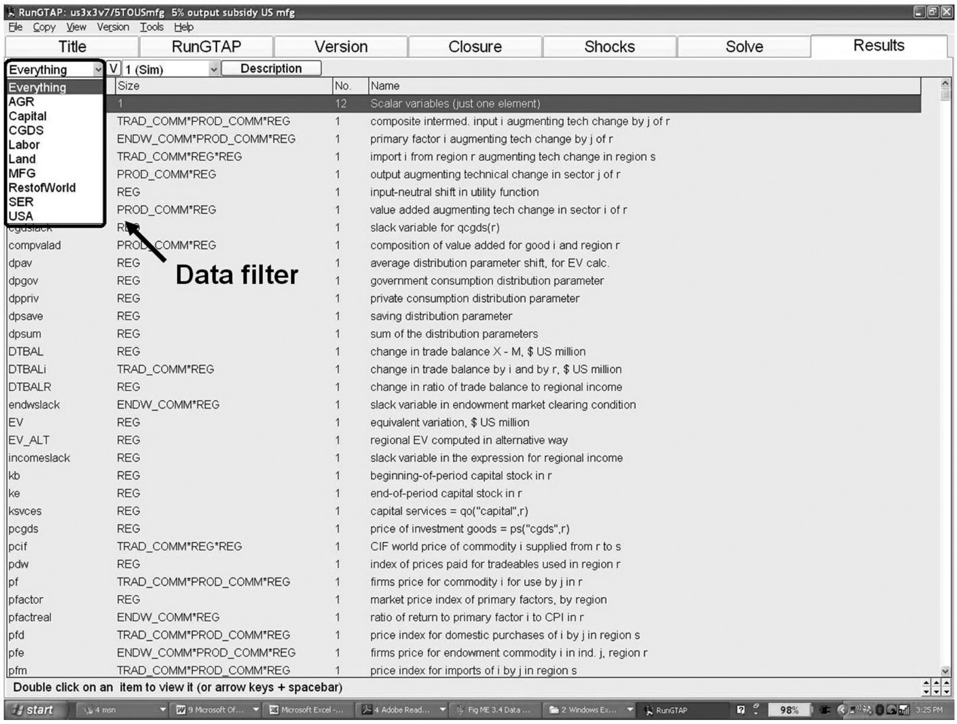


Figure ME 3.4. Data filter on the results page.

- Double-click on variable *qfe* and report results for labor demand in MFG for the USA in the “Base results” column of Table ME 3.2
- Double-click on data anywhere in the table to return to the variable list.

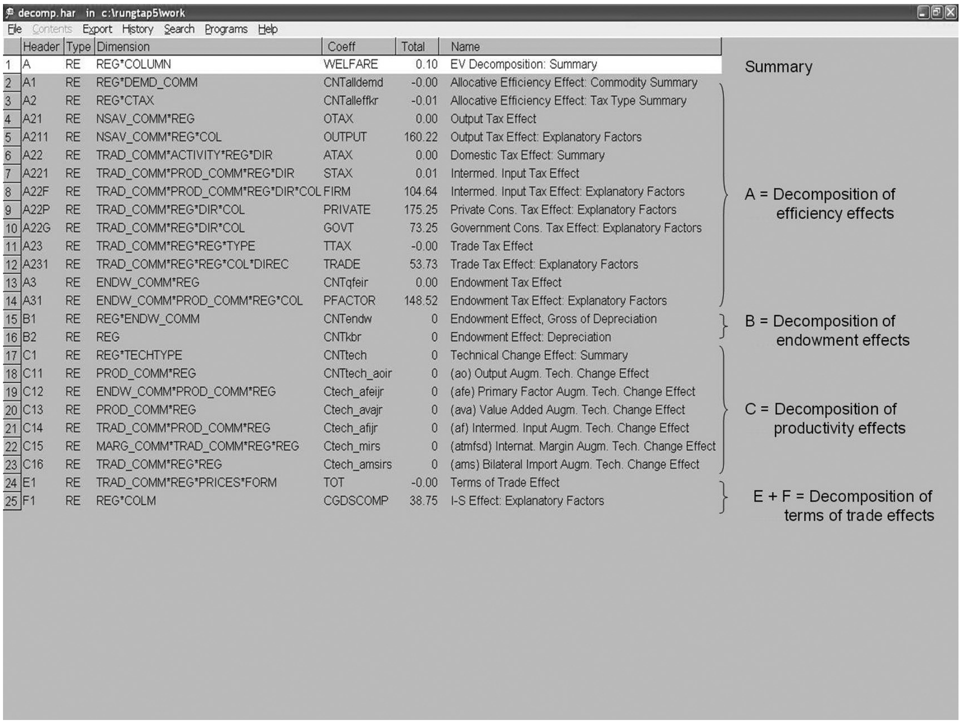
F. Find and Report Welfare Decomposition Results

The GTAP model includes a utility that decomposes the equivalent variation (EV) welfare effect of an economic shock. We discuss welfare measures in detail in Chapter 4. The utility disaggregates the total welfare effect into

Table ME 3.2. *Results of a 10% Production Subsidy in U.S. Manufacturing, with Different Elasticities and Closures*

Name of Variable	Definition of Variable	Base Results	High Factor Substitution Elasticity in MFG	Unemployment Closure
qo(“MFG”, “USA”)				
qo(“MFG”, “ROW”)				
qfe(“LABOR”, “MFG”, “USA”)				

Source: GTAP model, GTAP v.8.1 U.S. 3×3 database.



decomp.har in c:\rungtap5\work

File Contents Export History Search Programs Help

	Header	Type	Dimension	Coeff	Total	Name
1	A	RE	REG*COLUMN	WELFARE	0.10	EV Decomposition: Summary
2	A1	RE	REG*DEMD_COMM	CNTalldemd	-0.00	Allocative Efficiency Effect: Commodity Summary
3	A2	RE	REG*CTAX	CNTalleffkr	-0.01	Allocative Efficiency Effect: Tax Type Summary
4	A21	RE	NSAV_COMM*REG	OTAX	0.00	Output Tax Effect
5	A211	RE	NSAV_COMM*REG*COL	OUTPUT	160.22	Output Tax Effect: Explanatory Factors
6	A22	RE	TRAD_COMM*ACTIVITY*REG*DIR	ATAX	0.00	Domestic Tax Effect: Summary
7	A221	RE	TRAD_COMM*PROD_COMM*REG*DIR	STAX	0.01	Intermed. Input Tax Effect
8	A22F	RE	TRAD_COMM*PROD_COMM*REG*DIR*COL	FIRM	104.64	Intermed. Input Tax Effect: Explanatory Factors
9	A22P	RE	TRAD_COMM*REG*DIR*COL	PRIVATE	175.25	Private Cons. Tax Effect: Explanatory Factors
10	A22G	RE	TRAD_COMM*REG*DIR*COL	GOVT	73.25	Government Cons. Tax Effect: Explanatory Factors
11	A23	RE	TRAD_COMM*REG*REG*TYPE	TTAX	-0.00	Trade Tax Effect
12	A231	RE	TRAD_COMM*REG*REG*COL*DIREC	TRADE	53.73	Trade Tax Effect: Explanatory Factors
13	A3	RE	ENDW_COMM*REG	CNTqfeir	0.00	Endowment Tax Effect
14	A31	RE	ENDW_COMM*PROD_COMM*REG*COL	PFACTOR	148.52	Endowment Tax Effect: Explanatory Factors
15	B1	RE	REG*ENDW_COMM	CNTendw	0	Endowment Effect, Gross of Depreciation
16	B2	RE	REG	CNTkbr	0	Endowment Effect: Depreciation
17	C1	RE	REG*TECHTYPE	CNTtech	0	Technical Change Effect: Summary
18	C11	RE	PROD_COMM*REG	CNTtech_aoir	0	(ao) Output Augm. Tech. Change Effect
19	C12	RE	ENDW_COMM*PROD_COMM*REG	Ctech_afeijr	0	(afe) Primary Factor Augm. Tech. Change Effect
20	C13	RE	PROD_COMM*REG	Ctech_avajr	0	(ava) Value Added Augm. Tech. Change Effect
21	C14	RE	TRAD_COMM*PROD_COMM*REG	Ctech_afijr	0	(af) Intermed. Input Augm. Tech. Change Effect
22	C15	RE	MARG_COMM*TRAD_COMM*REG*REG	Ctech_mirs	0	(atmfsd) Internat. Margin Augm. Tech. Change Effect
23	C16	RE	TRAD_COMM*REG*REG	Ctech_amsirs	0	(ams) Bilateral Import Augm. Tech. Change Effect
24	E1	RE	TRAD_COMM*REG*PRICES*FORM	TOT	-0.00	Terms of Trade Effect
25	F1	RE	REG*COLM	CGDSCOMP	38.75	I-S Effect: Explanatory Factors

Figure ME 3.5. Welfare decomposition utility in the GTAP model.

six components: resource allocation (efficiency) effects (the excess burden of taxes), endowment effects due to changes in factor supplies, technical change due to productivity gains or losses, the effects of population growth, changes in terms of trade for goods and for savings and investment flows, and changes in preferences (the structure of aggregate demand). Welfare effects are reported in levels, in \$U.S. millions.

1. Open the GTAP welfare decomposition utility:
   - Select "View" from the menu bar
   - Select "Updated Data" from the drop-down menu
   - Select "Welfare Decomposition" from the drop-down menu

This page lists the full decomposition of EV (Figure ME 3.5).

2. View the summary of the welfare decomposition.
   - Double-click on first row: EV Decomposition Summary.
   - Report the welfare impacts of the 10% output subsidy in U.S. manufacturing in Table ME 3.3. *with the default elasticity parameters*. As a check, the first element, "Resource allocation effect," is already reported in the table.
   - Double-click anywhere on the page to return to the main EV decomposition page.
3. View the detailed welfare decomposition

Table ME 3.3. *Welfare Decomposition of a 10% Production Subsidy in U.S. Manufacturing*

Resource Allocation Effect	Endowment Effect	Technical Change	Population Growth	Terms of Trade	Investment-Savings Terms of Trade	Preference Change	Total
1 alloc_A1 12,721	2 endw_B1	3 tech_C1	4 pop_D1	5 tot_E1	6 IS_F1	7 pref_G1	

Source: GTAP model, GTAP v.8.1 U.S. 3×3 database.

The main welfare decomposition page, shown in Figure ME 3.5, lists all available decompositions. For example, all of rows with header names that begin with A list decompositions of allocative efficiency effects, by type of tax and by commodity. All rows with header names that start with C list decompositions of the productivity effect, and so on. You can view any decomposition in the list by clicking on it.

G. Export Model Results to Excel

You may want to compare the results of two experiments, but the GTAP model only reports results for one experiment at a time. The easiest way to save and compare selected results is to export results, one variable at a time, to your clipboard and paste them into an Excel file that identifies the experiment that generated the results.

After running an experiment,

- Select the "Results" page tab
- Double-click on the variable that you want to display
- Select "Copy" from the upper menu bar (this copies the results to your clipboard)
- Open Excel and paste your results into your file
- Label the results with the name of your experiment.

H. View and Change an Elasticity Parameter

Elasticities are the exogenous parameters used in model equations to define the responsiveness of supply and demand to changes in prices or income. A change to an elasticity parameter is not an experiment or "shock." It changes the model itself and how producers and consumers are assumed to respond to a shock. For instance, you might define a shock to be a new tariff on imports. You can run the experiment using the model's base elasticity values, and then run it again using a model with larger or smaller elasticity values. You then compare the results of the *same experiment* across two (or more) models with different assumed elasticity values.

This exercise shows you how to change an elasticity in the GTAP model from its default values and save it in a new parameter file. In this example,

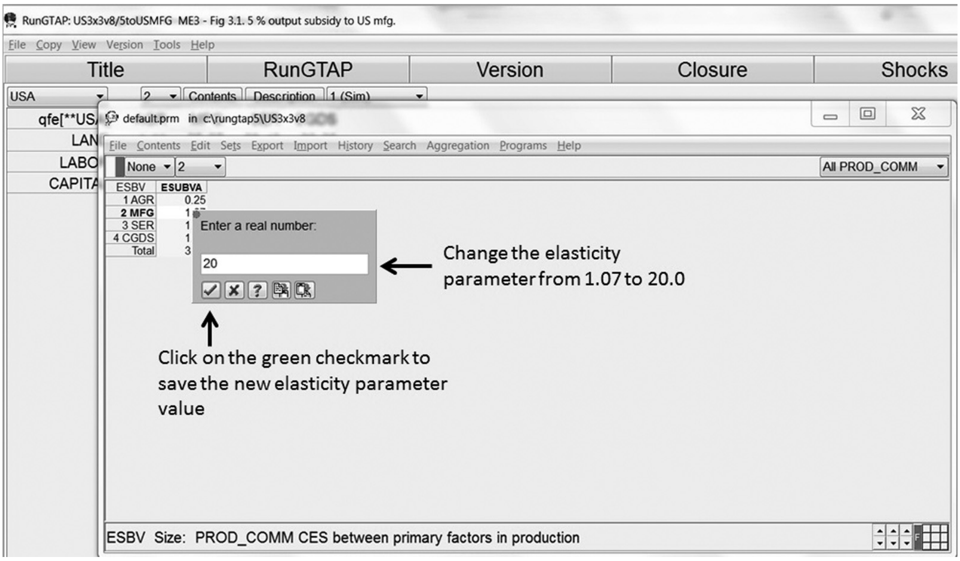


Figure ME 3.6. Changing an elasticity parameter.

you will change the factor substitution elasticity in U.S. manufacturing. Note that in the GTAP model, the factor substitution elasticity for each industry is the same for all countries in the model. You can use these same steps to change any elasticity in the GTAP model.

1. Define the new parameter values
   - Select “View” on the menu bar
   - Click on “Parameters” from the drop-down menu. This opens a HAR file with the elasticity parameters.
   - In the HAR file, select
     > File
     > Click on “Use Advanced, editing menu” from the drop-down menu. This step allows you to edit and save parameters.
   - Double-click on ESUBVA (the elasticity of factor substitution)
   - Right click on the data entry for MFG ESBUVA (see Figure ME 3.6)
   - Enter new ESUBVA value in manufacturing of “20”
   - Click on the green check mark to save the new elasticity parameter value on this sheet. But be careful: this does not save a new parameter file – see the next step. (You may get an error message that “You modified the file but need a GEMPACK license.” You may safely ignore the warning for this exercise.)
2. Save your new parameter file
   - Select “File” (in the ESUBVA window)
   - Close
   - Yes (answers the prompt “Save Changes?”)
   - IMPORTANT: do not overwrite your default parameter file. In the box, provide a new file name with a .prm suffix, such as “20vaMFG.prm.”

- Click on "Save." This step saves your new parameters in a file in your model version folder in the RunGTAP5 directory.
- OK.

3. Re-solve the model with a new elasticity
   - Select the "Solve" page tab
   - Check that the experiment description box describes "10toMFG," which means that your experiment is loaded and ready to run
   - If a different experiment is described, select "Load Experiment" and click on "10toMFG" and then click on OK to load the experiment 10toMFG
   - Click on "Change" next to "Parameter file:Default" in the upper right corner of the page
   - Select the name of your new parameter file: 20vaMFG
   - OK. (Your experiment file will now always use your new parameter file unless you change this selection.)

You have two options for saving your experiment and parameter file. One is to save a new version of your experiment, with a new name, which signals that this experiment uses a different parameter file. In the next several steps, we describe how to do this. Because this can create file clutter, an alternative is to reuse a single experiment, while always checking to see which parameter file is specified. That is the approach we follow in the remaining model exercises.

- Click on "Save Experiment"
- Give your experiment a new name, to indicate that this version uses different elasticity parameters than your original experiment. Name it something like: "10toMFG2" and describe it as "10toMFG with 20 ESUBVA in MFG."
- OK
- Solve.

4. Report new model results in Table ME 3.2, following the same instructions as in section E of this model exercise.

I. Change Model Closure

Model closure statements define which variables adjust (i.e., which are endogenous) and which are fixed (i.e., which are exogenous). To modify the model's standard closure statements, you must "swap" an exogenous variable for an endogenous variable. This swap preserves the same number of endogenous variables that were originally in the model.

In this exercise section, you will modify the labor market closure. The default closure has an exogenous, fixed national supply of labor (*qo*) and an endogenous economywide real wage (*pfactreal*). You will change the closure to swap the labor supply variable with the wage variable. Note that we are changing the closure statement for one factor market (labor) in one country (USA), as shown in Figure ME 3.7.

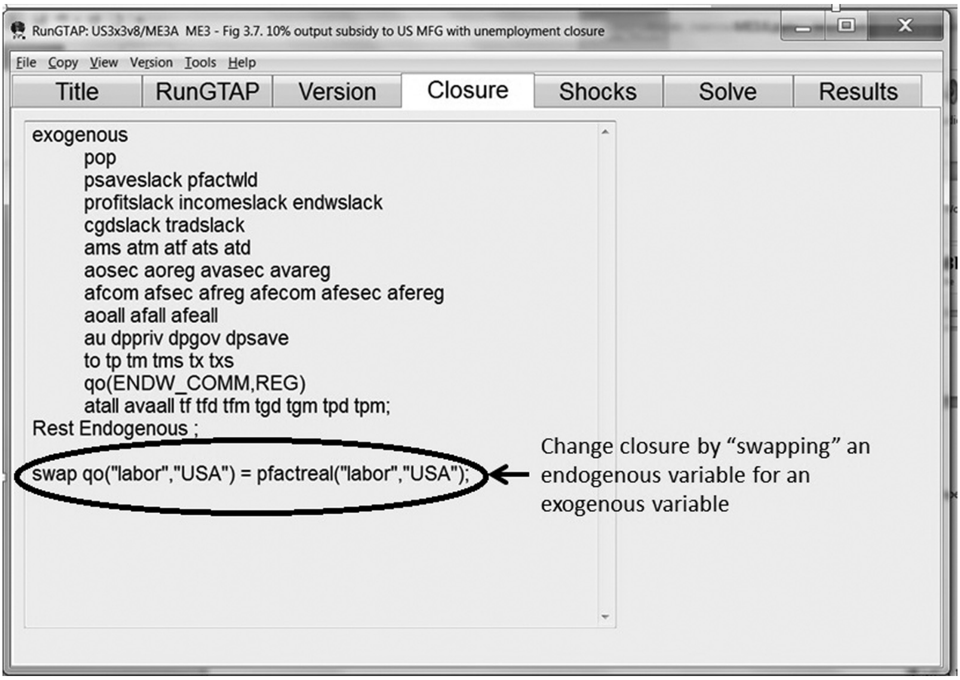


Figure ME 3.7. Changing the labor market closure.

1. Select the Solve page
    - Open the experiment file “10toMFG”
    - Click on the “Load Experiment” button
    - Select the experiment “10toMFG”
    - OK
2. Select the “Closure” page tab
    - Insert the bolded text below the final line of the closure instructions – “Rest Endogenous” (see Figure ME 3.7):
    - **swap qo(“labor”, “USA”) = pfactreal(“labor”, “USA”);**
3. Select the “Solve” page tab
    - Check that the parameter file to be used is default.prm; if not, click on the “Change” button, select default.prm from the list, and click OK
    - Save experiment
    - Name it “toMFGun” and describe it as “10% output subsidy to US MFG with unemployment.” This step saves both the experiment and the new closure statement. You can now rerun this experiment at any time without having to respecify your new closure statement.
    - OK
    - Solve
    - OK
    - OK
    - Report new model results in Table ME 3.2.

Table ME 3.4. *Commonly Modified Closures in the GTAP Model*

Closure in GTAP Model	Explanation	Add this Model Code to Closure Statement
Factor unemployment	For a specified country r and factor f, allows the endowment of a factor to vary and fixes that factor's real price (i.e., wage relative to CPI).	swap qo(f,r) = pfactreal(f,r); *example:* *swap qo("labor", "USA") = ps("labor", "USA");*
Fixed balance of trade	For a specified country r, allows domestic savings to adjust to maintain a fixed ratio between the trade balance and national income.	Swap dpsave(r) = DTBALR(r); *example:* *swap dpsave("usa") = DTBALR("usa");*
Fixed world import price (small country assumption for country r)	For a specified country r, fixes world import prices (*pm* in trade partner, s) by swapping several slack variables in the trade partner country.	*Example:* *Closure to fix world price – pm in ROW swap walraslack = pfactwld;* *swap incomeslack("ROW") = y("ROW");* *swap profitslack(PROD_COMM, "ROW") = qo(PROD_COMM, "ROW");* *swap endwslack(ENDW_COMM, "ROW") = pm(ENDW_COMM, "ROW");* *swap tradslack(TRAD_COMM, "ROW") = pm(TRAD_COMM, "ROW");* *swap cgdslack("ROW") = pm(CGDS_COMM, "ROW");*
Tax replacement or balanced government budget	For a specified country r, sales tax on private commodity consumption (imports plus domestic) becomes endogenous to maintain a fixed ratio of indirect tax revenue to national income.	swap tp(r) = del_ttaxr(r); *example:* *swap tp("usa") = del_ttaxr("usa");*
Export quantity control	For a specified commodity and bilateral trade flow, fixes export supply to partner; endogenous export tax measures economic rent to exporting country.	swap qxs(i,r,s) = txs(i,r,s); *example:* *qxs("mfg", "usa", "row") = txs("mfg", "usa", "row");*
Import quantity control	For a specified commodity i and importing country r, an endogenous import tariff maintains fixed import quantity.	swap qiw(i,s) = tm(i,s); *example:* *swap qiw("mfg", "usa") = tm("mfg", "usa");*
Variable import levy	For a specified commodity i and importing country r, an endogenous import tariff maintains a fixed ratio between the domestic market price and its world import price	Swap pr(i,r) = tm(i,r); *example:* *swap pr("mfg", "usa") = tm("mfg", "usa");*
Insulate domestic production levels from world market conditions	For a specified commodity i and country r, an endogenous export subsidy varies to maintain a fixed domestic production level.	swap qo(i,s) = tx(i,s); *example:* *swap qo("mfg", "usa") = tx("mfg", "usa");*
Change in government consumption	Fix and then change the exogenous level of government spending in country r, with shares of consumption and savings adjusting to maintain regional income = expenditure	swap dpgov(r) = ug(r); *example:* *swap dpgov("USA") = ug("USA");*

4. Do results of your experiment change when the elasticity or model closure statement changes?

Table ME 3.4 lists commonly used closure modifications in the GTAP and their related swap statements.

J. Systematic Sensitivity Analysis and Stochastic Shocks

The GTAP model includes a utility developed by Arndt and Pearson (1998) that automates a systematic analysis of the sensitivity of model results to the assumed values of elasticity parameters or to the size of an experiment shock.[2] To test the sensitivity to elasticity values, the modeler chooses which elasticity parameter(s) to test and specifies the range of values over which each will be tested. For example, the modeler may have assumed a value of two for the import substitution elasticity, but wants to test the sensitivity of model results if the elasticity's value ranges between 50% and 150%. The utility reports an estimate of the mean and standard deviation of results for every variable in the model as the elasticity value ranges between one and three.

A test of the sensitivity of model results to variability in model shocks is carried out in a similar way. In this case, the modeler defines a possible range for the variable that is being shocked. For example, the modeler may be studying the effects of climate change on productivity in agricultural production, which he has described in the model as a negative 10% shock to agricultural land productivity. If estimates of productivity losses vary widely in the literature, the modeler may want to test a range in productivity loss between 50% and 150% of the 10% decline. In this case, the sensitivity analysis would estimate the mean and standard deviation of model results for each variable, as the productivity shock ranges in value between –5% and –15%.

You can use the estimated means and standard deviations to calculate confidence intervals for your model result. We use Chebyshev's theorem for these calculations because it does not require us to assume anything about the shape of the probability distribution of the results for each variable (Text Box ME 3.1).

As an example, imagine that you carried out a model experiment for which you assumed an import substitution elasticity value of 2, with the result that output of good Q increases 19.1%. You then carried out a systematic sensitivity analysis to a range of between 50% and 150% of that elasticity value. Suppose your sensitivity analysis reports that the percent change in

[2] You need a GEMPACK license to carry out and view results from a systematic sensitivity analyses. You may download a free six-month limited license from the GEMPACK Web site at www.copsmodels.com/gpeidl.htm.

Text Box ME 3.1. Chebyshev's Theorem

At least the fraction $(1-(1/k^2)$ of any set of observations lies within k standard deviations of the mean, therefore:

a. 75% of the observations are contained in the interval QO_i
b. 88.9% of the observations are contained in the interval QO_i
c. 95% of the observations are contained in the interval $QO_{\text{“agriculture”}}$,
d. 99% of the observations are contained in the interval PS

output of good Q has an estimated mean of 19 and standard deviation of 1. Using Chebyshev's theorem, you can construct a 95% confidence interval. For example, the upper limit of a 95% confidence interval is 23.47 (19 + (4.47 ∗ 1). The lower limit is 14.53 (19 – (4.47 ∗ 1). Similarly, you can report with 75% confidence that the result lies between 21 and 17, which is 19 ± 2 (2 times the standard deviation of 1), and so forth.

Figure ME 3.8 plots these results on a graph. It shows the point estimate for the percentage change in output, which is the result reported in your model. It also plots the upper and lower limits of the 95% confidence interval that we calculated. Plotting model results along with confidence intervals is an effective way to visually communicate information about model sensitivity. In this case, a positive output change is a robust model result over the range that you specified for the value of the import substitution elasticity.

On the other hand, let's assume that your analysis reports a percentage change in the import quantity of good Q of 5%, with a mean of 5 and a

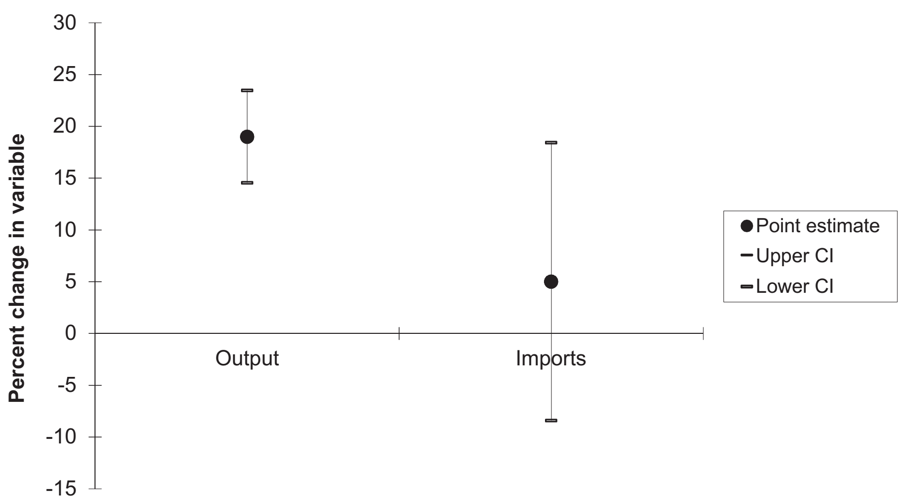


Figure ME 3.8. 95% confidence intervals for output and import quantity of good Q.

standard deviation of 3. Using Chebyshev's theorem, you have a 95% level of confidence that the percentage change in imports lies between 18 and –8, and a 75% level of confidence that the result lies between 11 and –1. In this case, you cannot be 95% confident or even 75% confident that imports increase, instead of fall, over your specified range of alternative elasticity parameter values.

The following steps will guide you in carrying out an analysis of the sensitivity of model results to the elasticity of factor substitution. A sensitivity analysis with respect to the size of an experiment shock is analyzed in the same way, so we do not repeat the instructions for that case. Our example is a systematic sensitivity analysis of the results of a 10% output subsidy in U.S. manufacturing to the value of the import substitution (ESUBVA) elasticity parameter.

1. In runGTAP, reload and rerun your experiment "10toMFG."
   - Go the to "Solve" page tab
   - Click on "Load Experiment" button
   - Select "10toMFG" experiment
   - OK
   - Check that parameter file to be used is default.prm; if not, click on the "Change" button, select default.prm from the list, and click OK
   - Solve
   - OK
   - OK.
2. Open the Systematic Sensitivity Analysis utility
   - Select "Tools" from the top menu bar
   - Select Sensitivity
   - Help on sensitivity. (This provides documentation and an intuitive explanation of this utility that you can use as a reference.)
   - Close the help document by clicking on the red X in the upper right corner of the file. This returns you to the GTAP model.
   - "Tools"
   - "Sensitivity"
   - "w.r.t. parameters" (the worksheet shown in Figure ME 3.9 will open)
   - Parameter to vary: ESUBVA
   - Elements to vary: ALL PROD_COMM
   - Percent variation: 100 (the sensitivity analysis will vary the ESUBVA elasticity parameter value between close to zero and two times the base parameter value, for all three goods in the model)
   - Type of variation: Percent (this is the default choice)
   - Type of distribution: triangular (it is similar to a bell curve distribution and is the default choice)
   - Select "Add to list"
   - OK

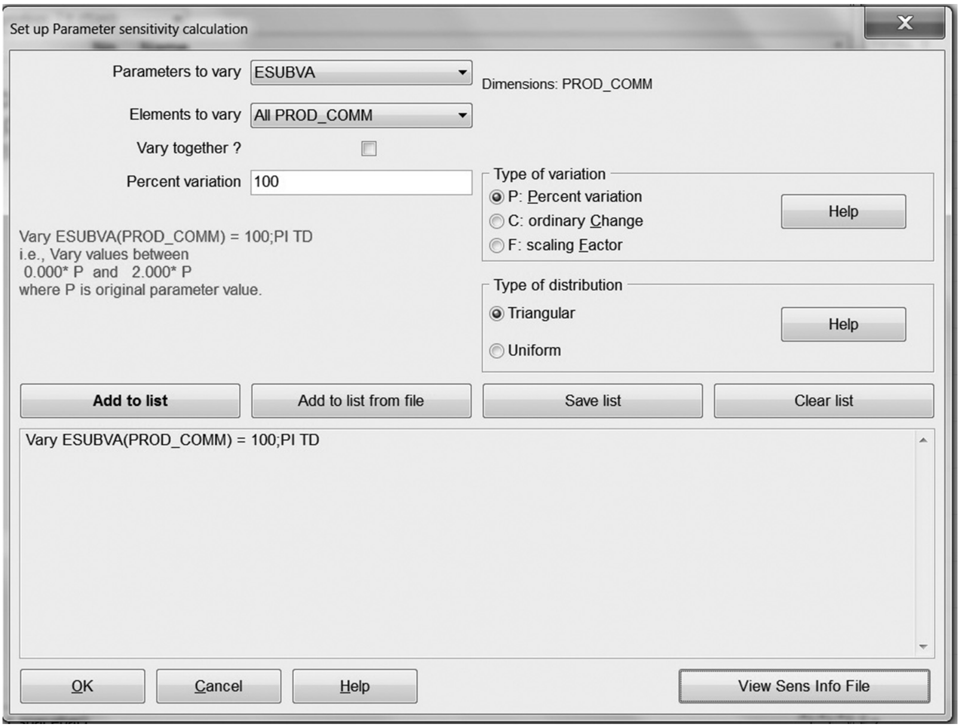


Figure ME 3.9. Systematic sensitivity analysis of an elasticity parameter.

- Select "Stroud" (this is the default choice. It defines the sampling of parameter values within the range that you specified.)
- OK (this starts the analysis)
- Yes (to the prompt "Do you want to save the two solutions reporting means and deviations?")
- OK (to the prompt asking you to name the two report files)
- You can accept the default name, or you may choose to rename the report files. If you define a name, it will be applied to all report files.
- Yes (this opens ViewSol utility, used to view the report files with the sensitivity analysis results).

3. Report results from the ViewSol file for U.S. manufacturing output, *qo*("MFG", "USA")
   - Filter results by selecting click on the "Everything" drop-down box on the upper left and selecting "USA." This selection consolidates the reports files and allows you to view the actual results, means and standard deviations for a U.S. variable all on one page.
   - Report the results
     a. Model result (reported in first column of data) ______________
     b. Mean (m1 – reported in second column of data) _______________
     c. Standard deviation (sd – reported in third column of data) _______________

Table ME 3.5. *Confidence Intervals for the Manufacturing Output Quantity Result with 100% Variation in the Factor Substitution Elasticity*

Confidence Interval	Mean (X)	Standard Deviation (sd)	Standard deviation Multiplier (K)	Upper Limit (X + sdK)	Lower Limit (X – sdK)
75%			2		
88.9%			3		
95%			4.47		
99%			10		

4. Construct confidence intervals using Chebyshev's Theorem, following the example in the first row of the table. Report them in Table ME 3.5. What is your level of confidence that the effect on U.S. manufacturing output is positive?

Model Exercise 4: Soaring Food Prices and the U.S. Economy

Concepts: Utility Function, Armington Import Demand, Factor Productivity

Background

In 2008, the prices of major agricultural commodities soared by more than 60% compared to their 2006 levels, after many years of relative price stability (Trostle, 2008). Prices abated when the global economy entered a recession, but some analysts view this price decline as temporary. They anticipate a long-term trend of rising food prices as future growth in global food demand outpaces growth in global supply.

Both short-term and long-term factors were at play in the skyrocketing of prices during 2008, according to Jeffrey Sachs, a noted Harvard economist writing for the *Scientific American*. On the demand side, rising world incomes have led to a steady increase in the demand for grains, because increased affluence leads to higher demand for meat. More grain must be used as feed, and the grain-to-food conversion ratio for meat is lower than when grain is consumed directly in products such as bread. China's rapid economic growth and the rising share of meat in the Chinese diet has been a major factor in this trend. Rising demand for feed affects not only the food-feed trade-off for grains; it has also led farmers around the world to grow more of the other necessary livestock feedstuffs, such as soybeans, instead of grains. On the supply side, short-term supply shocks that influenced prices in 2008 included Australia's deep drought and the U.S. policy to use corn for ethanol. In the longer term, climate change due to rising world temperatures is expected to change the suitability of land for its traditional agricultural uses, possibly leading to lower productivity in the supply of food.

Given the multiple causes of the potential imbalance between world supply and demand for food in the long term, economists have called for multipronged solutions (Cline, 2007; Collier, 2008). Their proposals include increasing research to raise agricultural productivity, particularly in developing countries where climate change is expected to have the most severe consequences for farming. Other recommendations are for policy change in the United States to end the diversion of corn into ethanol; an end to the European Union ban on imports of high-productivity, genetically modified food products; and global action on mitigating the long-term threat of climate change.

How will long-term rising food prices affect U.S. households' demand for food and the composition of their consumption basket? Will U.S. welfare rise or fall? How might this demand change affect U.S. industry structure and trade? In this exercise, you will simulate a 50% increase in the world price of agricultural products imported to the United States and use your model results to answer these and other questions. You will also analyze the sensitivity of your results to alternative assumptions about U.S. consumer preferences.

Experiment Design

You will run a single model experiment – an approximate 50% increase in the global price of agricultural products. This experiment will describe its cause as a negative supply shock in the rest-of-world. (Model Exercise 10 demonstrates how to model demand shocks.) The size of the price shock is slightly smaller than the 60% world price increase reported by Trostle (2008). We scale the price effect downward because our single agricultural sector includes commodities and natural resources not studied by Trostle; but for illustrative purposes, we still assume a relatively large price shock.

You will run the same model experiment twice, assuming two different utility functions. In the first experiment, scenario 1, you will use the GTAP model's CDE demand system with the default consumer demand elasticity parameters in the U.S. 3×3 database. In scenario 2, you will modify the consumer's utility function by changing the INCPAR and SUBPAR parameters to replicate those of a Cobb-Douglas utility function. INCPAR is the income parameter and SUBPAR is the compensated, own-price demand parameter.

Instructions

1. Open GTAP model with U.S. 3×3 database

   This step opens the "version" of the GTAP model that uses the U.S. 3×3 database. You created this version of the model in Model Exercise 1.

   - Open RUNGTAP
   - On the top menu bar, choose "Version"
   - "Change"
   - Select "US3×3"
   - OK.
2. Prepare your model to run an experiment – check closure
   - Select the "Closure" page tab.

Check that no closure changes are lingering there. The closure should end with "Rest Endogenous." If not, erase all text below that line.

3. Prepare your model to run an experiment – check shocks
   - Select "Shocks" page tab
   - Clear shock list

     This check ensures that there are no shocks lingering in your experiment file other than those you want to introduce.

4. In Table ME 4.1, report your model's base parameter values for INCPAR and SUBPAR for the United States for scenario 1. (See Model Exercise 2 for instructions on exploring elasticity parameters.)

Table ME 4.1. *Elasticities in Two Scenarios of a 50% Increase in the World Agricultural Price*

	Scenario 1		Scenario 2	
Elasticities	INCPAR	SUBPAR	INCPAR	SUBPAR
Agriculture				
Manufacturing				
Services				

5. In Table ME 4.2, report base budget shares of each commodity in household expenditure.
   - Select “View” from the upper menu bar
   - “Base data” from the drop-down menu
   - “GTAPView Output”
   - Double-click on row “NVPA” which reports the cost structure (which are budget shares) of private household consumption
   - Open the drop-down menu at top left, next to the box that says “None”
   - Select “COL” from the drop-down box. This reports each cell as a percentage of the column total. In this case, the matrix now reports the shares of each commodity in total private household spending. Report the data for the U.S. household.
   - Click on the large red X in the upper left to close the ViewHar file.
6. Define your model experiment: Increase in world price of AGR
   - Select Shock page table
   - Variable to shock: “afeall” – this is the productivity of land, which declines in this supply shock experiment
   - Elements to shock: “LAND”, “AGR,” “ROW”; this changes productivity only in ROW
   - % change shock: –81%
   - Add to shock list.
7. Change solution method and save the experiment
   - Select the “Solve” page tab
   - On the solve page, the solution method should be Johansen. If it is not, click on “Change.” Select Johansen and then click on “OK.”Your model will now solve for a single linear solution. This is useful for pedagogical purposes, but

Table ME 4.2. *Household Budget Shares*

Base	Scenario 1	Scenario 2
Agriculture	.009	
Manufacturing		
Services		

Table ME 4.3. *Effects of a 50% Increase in the World Agricultural Price (% change from base)*

	World price	Consumer Price	Consumer Composite Commodity Quantity	Consumer Domestic Quantity	Consumer Import Quantity	Production Quantity
GTAP variable name	*Pxwcom*	*pp*	*Qp*	*Qpd*	*Qpm*	*Qo*
CDE utility						
Agric.						
Mfg.						
Services						
Cobb-Douglas						
Agr.						
Mfg.						
Services						

a multistep solution method is likely to be more accurate for your applied research. (See the discussion of linearization in Chapter 2.)

- On the solve page, check that the parameter file is "Default." If it is not, click on "Change," select "Default" from the box, and click on "OK."
- Click on "Save Experiment," name the shock "PWAgr1," and describe it as 50% increase in world price of AGR with default CDE utility function.

8. Solve the model
   - Click on "Solve"
   - OK
   - OK.
9. Report model results for the United States in Table ME 4.3.
10. Report your results for new budget shares
    - Select "View" from the upper menu bar
    - "Updated data" from the drop-down menu
    - GTAPView Output
    - NVPA (Row 16) this reports the updated commodity composition of household consumption
    - Select the drop-down menu for the box at top left, the one that says "None"
    - Select "COL"; this reports each cell as a share of the column sum. These are the updated shares of each commodity in total private household spending. Report the data for the U.S. household in Table ME 4.2.
11. Change your utility function parameters to replicate a Cobb-Douglas function (see Model Exercise 3 for instructions on how to change elasticity values and save a new parameter file).
    - Set all INCPAR for the United States and rest-of-world equal to exactly one
    - Set all SUBPAR for the United States and rest-of-world equal to exactly zero
    - Save your new parameter file as "3×3CobbDouglas.prm."

12. View, and report in Table ME 4.1, your model's new parameter values for INCPAR and SUBPAR for the United States for scenario 2.
13. Save your experiment and rerun the model with the new parameter values
    - Select the "Solve" page tab
    - Click on the "Change" button next to "Parameter file: default" in the upper right corner
    - Select "3×3CobbDouglas" from the list
    - OK
    - Click on "Save Experiment," name the shock "PWAgr2", and describe it as an increase in world price of AGR with Cobb-Douglas utility function
    - Click on "Solve"
    - OK
    - OK.
14. Report your new model results in Tables ME 4.2 and ME 4.3.

Interpret Model Results

1. Compare the assumptions of the two utility functions in your CGE analysis about own-price elasticities of demand for agriculture (Table 4.3). How do you anticipate the price increase will affect the quantity of private consumer demand for the composite commodity (imports plus domestic) AGR in both scenarios? Is this expectation consistent with the results of your general equilibrium model for both scenarios? In which utility function are consumers more own-price sensitive?
2. Compare the income effects implied by the utility functions and their parameter values, used in each scenario. Are the functions homothetic? For each utility function, describe whether each of the three goods are a necessity or a luxury, or if its demand quantity changes by the same proportion as income. Household income (*yp*) increase by about 1.4% in both experiments. Which utility function is likely to drive a larger increase in household demand for AGR as a result of the income change?
3. The elasticity of substitution between two goods is calculated as the percentage change in the quantity ratio of X to Y, relative to the percentage change in the price ratio of Y to X. (Hint: recall Text Box 2.1 on how to calculate the percentage change in a ratio.) The elasticity of substitution of the Cobb-Douglas utility function has a value of –1. Use model results for consumer price (*pp*) and private composite consumption (*qp*) from the experiment with the Cobb-Douglas utility function to calculate the elasticity of substitution between AGR and MFG. Are your model results consistent with the assumptions of your utility function?
4. How do changes in budget shares spent on agriculture compare in the two scenarios? Explain these results using your knowledge of the two different utility functions.
5. Most discussion of the world agricultural price shock focuses on consumers. How will the world price shock affect producers and the industrial composition of the U.S. economy? Can you explain why?

6. What is the Armington assumption? What is the import-domestic substitution elasticity (ESUBD) for AGR in your model? Given this assumption and parameter value, how do you expect U.S. demand quantities for AGR imports relative to demand for domestic goods will respond when the world price increases by about 50%? Is this expectation borne out by model results in both scenarios?

Model Exercise 5: Food Fight: Agricultural Production Subsidies

Concepts: Production Function, Production Subsidy, SUBTOTAL, Factor Substitution Elasticity

Background

"Farm subsidies have outlived their usefulness," according to Robert Samuelson, the economic columnist for the *Washington Post* and *Newsweek*. In a recent column, "The Endless Foodfight," Samuelson argued that the original goals of farm subsidy programs have been met in the United States and other high-income countries. In the United States, agricultural subsidies were introduced in the depths of the Great Depression in order to raise incomes in rural areas and keep food prices low. Although there have been some modifications in the subsidy program over the years, the United States still provides production subsidies to its agricultural producers. Yet, conditions for farmers today are much different than they were in the 1930s. U.S. farm households now earn as much or more than the average urban U.S. household, and food accounts for only a small share of the budget of the average American family. Some people may advocate subsidies as a strategy to ensure that the United States maintains its ability to feed itself and avoids dependence on food imports. However, growing food imports by the United States largely reflect Americans' rising standard of living. Imports provide U.S. consumers with specialized agricultural and food products and year-round access to seasonal produce.

Subsidies are costly and governments pay for them by levying taxes on other parts of the economy. Agricultural subsidies in the United States and other high-income countries have an additional cost – they jeopardize the success of global negotiations on trade liberalization, sponsored by the World Trade Organization (WTO). The countries' use of agricultural subsidies is thought to distort global markets by increasing their farm production and lowering world agricultural prices, thereby creating unfair competition for farmers in other countries. As long as high-income countries' agricultural subsidies remain in place, many of their trade partners are unwilling to lower their tariffs and allow greater entry to these and other exports from high-income countries. The stalemate over agricultural subsidies contributed to the breakdown of the WTO negotiations in 2008.

If farm subsidies have outlived their usefulness and are increasingly costly, why do the United States and other high-income countries continue to use them? In this model exercise, you will conduct an experiment in which you eliminate all U.S. agricultural subsidies, which include production subsidies, intermediate input subsidies, and land use subsidies. Experiment results will illustrate the costs and benefits of agricultural subsidies in the United States and provide some insight as to why it is so hard to eliminate them.

Experiment Design

What is the effect of an existing tax or tariff on an economy? One way to measure its effect is to remove it. The difference between an economy with and without the tax or subsidy provides a measurement of its economic impact.

In this exercise, you will calculate the cost of U.S. agricultural taxes and subsidies in a single experiment that:

1. Eliminates all production taxes/subsidies;
2. Eliminates all land-based factor use subsidies; and
3. Eliminates all subsidies on the purchase of intermediate inputs by agricultural producers.

You will then use SUBTOTAL, a GTAP utility that allows you to decompose the results of each component of this multipart experiment.

Instructions

1. Open the GTAP model with U.S. 3×3 database
   This step opens the "version" of the GTAP model that uses the U.S. 3×3 database. You created this version of the model in exercise 1.
   - Open "RUNGTAP"
   - On the top menu bar, choose "Version"
   - Change
   - Select "US3×3"
   - OK.
2. Prepare your model to run an experiment – check closure
   - Select the "Closure" page tab.

     Check that no closure changes are lingering there. The closure should end with "Rest Endogenous." If not, erase all text below that line.
3. Prepare your model to run an experiment – check shocks
   - Select "Shocks" page tab
   - Clear shock list

     This check ensures that there are no shocks lingering in your experiment file other than those you want to introduce.
4. Eliminate output tax/subsidies in U.S. agriculture (*to*, "AGR", "USA")
   - Choose "Shocks" page tab
   - From the drop-down menu "Variable to shock," choose variable "*to*"
   - Select these elements of *to*: AGR and USA.
   - Note the initial *ad valorem* (AV) tax rate. (A negative value indicates a tax.) Write the rate down in Table ME 5.1.
   - Set a shock value of zero
   - Select "Type of shock: % target rate"
   - Click on "Add to shocks list."

Table ME 5.1. *Base and Updated Subsidy Rates in U.S. Agriculture*

	Base Rate	Updated Rate
Production (output) subsidy/tax		
rto("AGR", "USA")		
(negative value = tax)		
Land tax		
rtf("LAND", "AGR", "USA")		
(negative value = subsidy)		
Tax on firms' purchase of domestically-produced intermediate input used in AGR		
rtfd("AGR", "AGR", "USA")		
(negative value = subsidy)		
Tax on firms' purchase of imported intermediate input used in AGR		
rtfi("AGR", "AGR", "USA")		
(negative value = subsidy)		

5. Define output tax elimination as a "Subtotal" in your results
   - Click on "Define subtotal" button

     This opens a dialogue box, shown in Figure ME 5.1, where you define each subtotal. You can wait and define all of your subtotals after you have finished setting up your experiment file, or you can define each subtotal after selecting each part of your shock, as we do in these instructions.

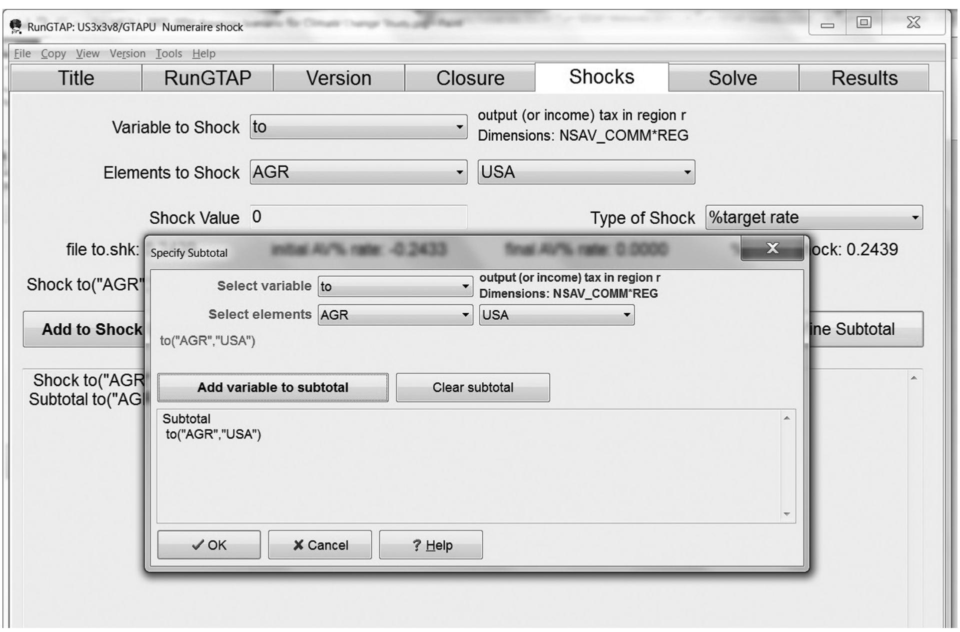


Figure ME 5.1. Define subtotals of a model shock.

- Select variable: *to*
- Select elements: "AGR" and "USA"
- Click on "Add variable to the subtotal"
- OK
- Name it "AGR output subsidy"
- OK

6. Eliminate the factor use subsidy on land use, *tf*, used in U.S. AGR by setting *tf* for elements LAND, AGR, USA to zero (target rate = 0). Note the initial AV percent tax rate for *tf* and write it in Table ME 5.1.
7. Define the elimination of the land use subsidy as a subtotal in your results, named "Land subsidy"
8. Eliminate all input subsidies on domestically produced intermediate inputs, *tfd*, for elements All TRAD_COMM, AGR, USA by setting *tfd* to zero (target rate = 0).
9. Eliminate all input subsidies on imported intermediate inputs, *tfm*, for elements All TRAD_COMM, AGR, USA by setting *tfm* to zero (target rate = 0)
10. Define the removal of both *tfd* and *tfm* as a subtotal in your results, named "Intermediate input subsidies"
11. Save the experiment
    - Select the "Solve" page tab
    - Check that the solution method is "Gragg 2-4-6." If it is not, click on "Change." Select Gragg and click on "OK."
    - Check that the parameter file is "Default." If it is not, click on "Change," select "Default" from the box and click on "OK."
    - Click on "Save" and name the shock "AgrSubs", describe it as "Elimination of US AGR subsidies."
12. Locate and view the base values for subsidies to U.S. agricultural firms on their purchases of domestic intermediate inputs
    - Click on "View" on the menu bar
    - Select "Base data" from the drop-down menu
    - Select "Tax Rates" from the drop-down menu
    - Select rTFD to display base *ad valorem* taxes to firms' purchases of domestic intermediate inputs
    - Select elements: All TRAD_COMM, AGR and USA in the upper right corner of the HAR file (Figure ME 5.2). In Table ME 5.1, report only the tax that is paid by agriculture on the agricultural input: rTFD("AGR", "AGR", "USA").
13. Repeat these steps to report subsidies on U.S. AGR purchases of imported intermediate inputs: rTFI("AGR", "AGR, "USA") in Table ME 5.1.
14. Solve the model
    - Click on the "Solve" page tab
    - Click on the "Solve" button
    - OK
    - OK.

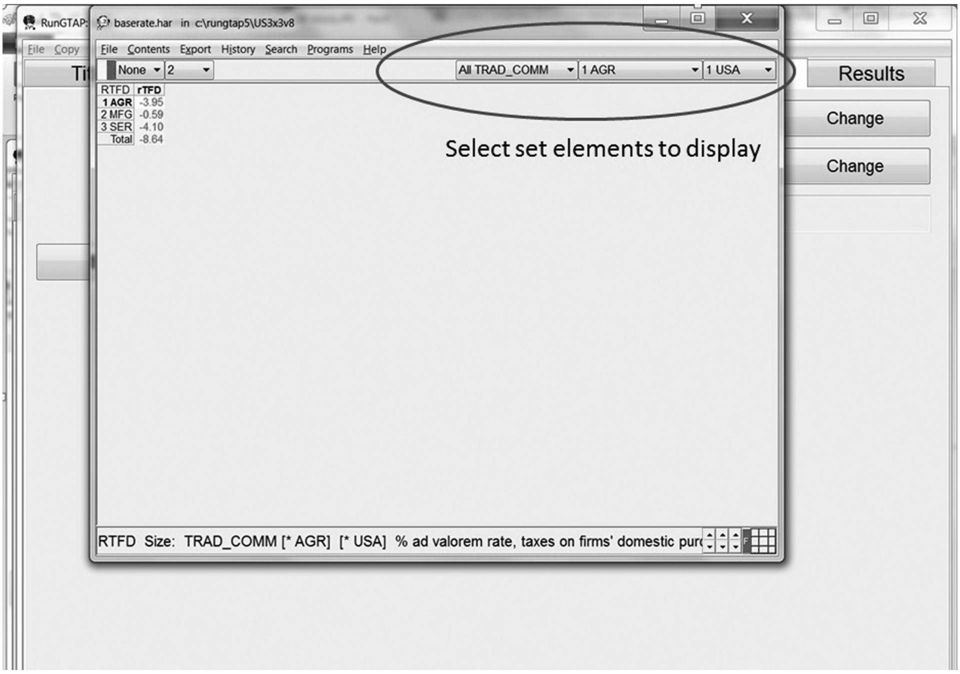


Figure ME 5.2. Select set elements to display for a tax with three dimensions tax.

15. Before viewing results, verify that your experiment has changed the tax rates as you expect by viewing the updated tax rates.
    - Click on "View" from the menu bar
    - Select "Updated data" from the drop-down menu
    - Select "Tax rates" from the drop-down menu
    - Report the new tax rates in Table ME 5.1, for each of the four taxes in this experiment. Select set elements in the upper right corner that correspond to the dimensions for each tax listed in Table ME 5.1.
16. Report model results in Table ME 5.2 and in the first column of Table ME 5.3. To view results decomposed into the subtotals, then, for example:
    - Click on the Results page tab
    - Click on the box labeled "Everything" in the upper left corner, and select "USA" from the drop-down menu
    - Click on variable *qo – industry output of commodity i in region r*.This will display the output quantity results for USA, with Subtotals labeled 1, 2, and 3.
    - Click on the Description box in the upper center of the page – its drop-down box will provide the descriptions of each of the numbered subtotals columns.
17. Follow the instructions in Model Exercise 3 to change the elasticity of factor substitution (ESUBVA) in AGR, MFG and SER to 12. After changing your experiment to run with the new parameter file, re-solve the model and report only the total effects in Table ME 5.2.

Table ME 5.2. *Effects of U.S. Agricultural Subsidy Elimination (% change from base)*

	Base ESUBVA Factor Substitution elasticity				ESUBVA = 12
		Subtotals			
Variable name in GTAP	TOTAL	Production Tax/Subsidy Effect	Land Tax/ Subsidy Effect	Intermediate Input Tax/ Subsidy Effect	TOTAL
Agricultural output quantity	*qo* (AGR,USA)				
Agricultural producer price	*ps*(AGR,USA)				
Land rent	*ps*(LAND,USA)				
Labor wage	*ps*(LABOR,USA)				
Capital rent	*ps*(CAPITAL,USA)				
Household consumption	*Qp*(AGR,USA)				
Export quantity	*qxw*(AGR,USA)				
Export price	*pxw*(AGR,USA)				

Interpret Model Results

1. Draw a technology tree for U.S. agriculture in the U.S. 3×3 model. Identify the inputs in each nest and the values in your model for the elasticity parameters that govern substitutability within each nest and at the top level.
2. Given the elasticity parameters in the AGR technology tree, explain how a change in relative input costs due to the policy reform could affect the ratios of intermediate and factor inputs used in U.S. agriculture.

Table ME 5.3. *Change in Input-Output Coefficients due to U.S. Agricultural Policy Reform (% change from base)*

Output and Inputs	Change in Outputand Input Quantities	Change inInput-Output Coefficients (*qfe-qo*) or (*qf-qo*)
AGR output (*qo*)	0.37	Not applicable
Land (*qfe*)		
Labor(*qfe*)		
Capital(*qfe*)		
AGR intermediate (*qf*)		
MFG intermediate (*qf*)		
SER intermediate (*qf*)		

3. In Table ME 5.3, use the results from the experiment with default parameter values to calculate the percentage changes in input-output ratios for each input. Describe the changes in input intensities. Are these findings consistent with your depiction and discussion of the technology tree in the questions 1 and 2? Are they consistent with the changes in your factor price results reported in Table 5.2?
4. In the default elasticity case, how does the total effect of U.S. policy reform on AGR output compare with reforms of each separate component? If you were a policy maker, how might the availability of subtotaled results influence your thinking on the best way to phase in the reform program?
5. Compare the total effects of all reforms using the default versus the high factor substitution elasticity. Are they different? Why? Do you think that your model results are highly sensitive to the factor substitution value that you choose for your analysis?
6. Based on data in the U.S. structure table, in Chapter 3, what is the share of food in households' total expenditure on goods and services? Given that expenditure pattern, what might be the views of U.S. consumers on agricultural subsidy reform?
7. Farmland is mostly owned by farming households and land rents are an important source of farm household income. Based on the change in land rents in your results, how do you think rural U.S. households will view subsidy elimination?
8. In the our simple 3×3 model, land is employed only in agriculture while labor and capital are fully mobile across all three sectors; and all factors are fully employed. Given this assumption, why do you think there is no change in agricultural output in the subtotal in which only the land factor use subsidy is removed?
9. Based on your model results, what is your view of the concern of U.S. trade partners that U.S. farm programs increase output and exports, which depresses world prices?

Model Exercise 6: How Immigration Can Raise Wages

Concepts: Factor Endowment Shocks, Factors as Complements and Substitutes, Factor Substitution Elasticity

Background

In 2014, there were 42 million immigrants living in the United States (U.S. Census Bureau, 2015). The United States is a nation of immigrants and historically has been a land of refuge and opportunity for foreigners. But with the number of immigrants now reaching more than 13% of the population, a contentious public debate has opened over the costs and benefits of the newcomers. On one hand, new workers add to the nation's stock of wealth, so the United States benefits from an increase in its productive capacity. On the other hand, new workers compete with native workers for jobs and may drive down wages – a key concern for U.S. labor. In addition, there are costs associated with the public services needed by immigrants that may not be sufficiently offset by the taxes that they pay.

The growing body of economic research on immigration offers conflicting results on their net impact on the U.S. economy and, in particular, its labor force. In a 2003 study, Dr. George Borjas concluded that immigration to the United States in the 1980s and 1990s reduced the average annual earnings of native-born workers by an estimated $1,700 or roughly 4%. Wages fell because employers can easily substitute immigrant labor for native U.S. workers in the same skill class. An immigrant auto mechanic, for example, can be substituted easily for a native-born auto mechanic. Dr. Borjas also accounted for the "cross-price effects" of immigration across skill classes. An increased number of auto mechanics, for example, leads to increased demand for native-born workers with complementary skills, such as dentists and teachers for the immigrants' children. But he found these cross-price wage benefits to be small. In a supply and demand framework, he concluded that the main effect of immigration has been to shift the labor *supply* curve outward for each skill class, causing the wages of native workers to fall.

Ottaviano and Peri (2012) disagree with Borjas. In their study of immigration to the United States since the 1990s, they found that immigration has increased the average U.S. wage by 1.8% and the average wage of American-born workers by 2.7%. Two factors are at work. First, they argue that immigrant and native-born workers are relatively poor substitutes in the workplace. Even when they have similar educations, they tend to choose different occupations and have different types of skills. For example, an immigrant auto mechanic is a poor substitute for a native-born health technician. As a result, immigration mainly depresses the wages of earlier immigrants.

Moreover, they found that cross-price effects are large, so that the increased number of immigrant auto workers has led to increased demand and higher wages for workers with complementary skills, like dentists and teachers. In a supply-and-demand framework, they argue that the dominant effect of immigration is to shift out the *demand* curve for native workers of all education levels.

A second factor, they argue, is that firms take advantage of the growing labor market by increasing their investment. In turn, new investment leads to increased demand for labor, a complementary factor to capital. In a supply-and-demand framework, an increase in the capital stock causes an outward shift in the demand for all labor types, which also helps boost wages.

Experiment Design

A key contribution made by the two studies was their authors' use of a general equilibrium framework to analyze the wage effects of immigration. Their studies took into account how wages in each labor market depended on its interaction with labor markets for other types of workers and, in the Ottaviano and Peri's study, with increased capital investment. This exercise is designed to help you control and manipulate your CGE model in order to deconstruct and replicate the underlying assumptions made in these two influential and competing views on the economic effects of U.S. labor immigration.

In this model exercise, you will carry out a simulation of the general equilibrium effects of immigration on the United States. Your analysis is comparatively limited because your CGE model will have only two labor markets, skilled and unskilled labor, and will not differentiate between native and immigrant workers. In addition, your experiments rest on the simplifying assumption that labor migration occurs only in the unskilled labor category, although both skilled and unskilled workers immigrate to the United States. In this exercise, you will:

1. Create a U.S. 3×3 model aggregation and model version that includes unskilled labor, skilled labor, and capital.
2. Develop small theoretical models to illustrate the assumptions about labor supply and demand underlying your analysis.
3. Carry out three experiments:

   BORJAS simulates a 10% increase in the unskilled labor supply, assuming that factors are highly substitutable.

   OTTA1 simulates the BORJAS experiment but assumes that factors are relatively complementary.

   OTTA2 adds to OTTA1 a 6% increase in the U.S. capital stock.

Instructions

1. Open GTAPAgg8ay07
2. From the menu bar, select "Read Aggregation Scheme from File"
   - Select the US3×3 aggregation file. This is a shortcut to creating a new 3×3 model, because regions and sectors in your database for this exercise remain the same as in the US3×3 database. If you did not create a U.S. 3×3 model, follow instructions in Model Exercise 1 to create a U.S. 3×3 database, and replicate the steps for "Define the country aggregation" and "Define the sector aggregation."
3. Define the factor aggregation
   - From the menu bar, select "View/change factor aggregation"
   - In the table at the bottom of the page, right-click to remove all but three factor rows
   - In the left column, type "UNSKILLED," "SKILLED," and "CAPITAL."
4. Define all factors as "mobile" in the column headed "ETRAE value or mobile."
5. Map factors into three-factor aggregation
   - Click on the "New factor" column of the mapping table in the upper right quadrant and pull down the mapping menu
   - Map: land to CAPITAL; unskilled labor to UNSKILLED, skilled labor to SKILLED; and capital and natural resources to CAPITAL
   - OK.
6. Save your data aggregation file
   - From the menu bar, select on "Save aggregation scheme to file." (GTAP provides a default name, "gtp3_2.agg," which you can change to something descriptive, like "Imm.agg"
   - Save this aggregation file in the folder that you created for your research project.
7. Create the aggregated database
   - From the menu bar, select "Create aggregated database." This creates a zip file with the aggregated database. Give it the same name as your aggregation scheme (e.g., Imm.zip), and save it in your project folder.
   - Close GTAPAgg7
   - Your database is now saved in zipped Header Array (HAR) files that are ready to use in your CGE model.
8. Create a GTAP model version for the immigration exercise following the instructions in Model Exercise 1. Give your model version the same name as your aggregation scheme and database (e.g., IMM).
9. The GTAP model will run a test simulation. It may fail if you are using the uncondensed version of the GTAP model. If so, click on "Tools" on the menu bar, and select "Run test simulation" from the drop-down box, and it will again run a test simulation.
10. Prepare your model to run an experiment – check closure
    - Select the "Closure" page tab

      Check that no closure changes are lingering there. The closure should end with "Rest Endogenous." If not, erase all text below that line.

11. Prepare your model to run an experiment – check shocks
    - Select "Shocks" page tab
    - Clear shock list
    - This check ensures that there are no shocks lingering in your experiment file other than those you want to introduce.
12. In the BORJAS scenario, you assume that factors can be substituted for each other relatively easily by changing the factor substitution elasticity to 12 for all industries (ESUBVA = 12). Follow instructions in Model Exercise 3 on how to change an elasticity parameter and save it in a new parameter file, named BORJAS.prm
13. Define the BORJAS model experiment
    - Variable to shock: "*qo*"
    - Elements to shock: "UNSKILLED," "USA"
    - % change shock: 10%
    - Select: Add to shock list.
14. Save the experiment file
    - Select the "Solve" page tab
    - Check that the solution method is Gragg 2-4-6. If it is not, click on "Change," select Gragg from the box, and then click on "OK."
    - Change your parameter file by clicking on "Change" next to "Parameter file: default," and select your new parameter file name, BORJAS.prm
    - OK (this closes your parameter file dialogue box)
    - Click on "Save experiment," name the shock BORJAS, describe and it as 10% increase in unskilled labor.

Table ME 6.1. *Effects of 10% Increase in the U.S. Supply of Unskilled Labor*

Factor	Factor Price (*pfe*)	Industry	Demand for Labor (*qfe*) Unskilled	Demand for Labor (*qfe*) Skilled	Output (*qo*)
BORJAS – 10% increase in unskilled labor supply, high factor substitution					
Unskilled labor		Agriculture			
Skilled labor		Manufactures			
Capital		Services			
OTTA1 – 10% increase in unskilled labor supply, low factor substitution					
Unskilled labor		Agriculture			
Skilled labor		Manufactures			
Capital		Service			
OTTA2 – 10% increase in unskilled labor, 6% increase in capital, low factor substitution					
Unskilled labor		Agriculture			
Skilled labor		Manufactures			
Capital		Services			

Table ME 6.2. *Real GDP Effects of a 10% Increase in U.S. Unskilled Labor Supply*

Scenario	% Change in Real GDP (*qgdp*)
BORJAS	
OTTA1	
OTTA2	

15. Solve the model
    - Click on "Solve"
    - OK
    - OK.

    Report your results in Table ME 6.1 and Table ME 6.2.
16. Create a new parameter file for OTTA1 and OTTA2 that describes factors as complementary by reducing the elasticities of substitution to:

    AGR = 0.2; MFG = 0.5; SER = 0.5 (the CGDS elasticity is irrelevant because this sector does not employ factors of production)

    Follow instructions in Model Exercise 3 on how to change an elasticity and save a new parameter file, named OTTA.prm.
17. Create the OTTA1 experiment file
    - Adapt the BORJAS experiment file to use the Otta.prm parameter file. On the Solve page, click on the "change" button next to "Parameter file." Select OTTA.prm.
    - OK
    - save the Borjas experiment as OTTA1
    - Select the "Solve" button, solve the model, and report your results in Tables ME 6.1 and ME 6.2.
18. Define OTTA2 experiment by adding capital stock growth to the OTTA1 experiment:
    - Variable to shock: "*qo*"
    - Elements to shock: "CAPITAL," "USA"
    - % change shock: 6%
    - Click on "Add to list"
    - Select the "Solve" page tab
    - Save the model experiment and name it OTTA2
    - Select the "Solve" button, solve the model, and report your results in Tables ME 6.1 and ME 6.2.

Interpret Model Results

1. Develop a theoretical model to describe the Borjas argument. Draw a graph for each labor market, identifying the supply and demand curves and the initial equilibrium quantities and wages. In the graph of the unskilled labor market, show the effects of unskilled labor immigration on wages and employment. Which curve

shifts? In the graph of the skilled labor market, show the effect of the increased supply of unskilled workers. Which curve shifts? In which direction will it shift if the two types of labor are substitutes, as argued by Borjas?

2. How did you change the CGE model to represent factors as substitutes or as complements? What does a larger parameter value signify?
3. Are the wage results of the BORJAS experiment consistent with those of your theoretical model? Why are the effects of immigration on skilled wages and capital rents negative when factors are good substitutes?
4. Develop a theoretical model to describe the Ottaviano and Peri's argument. Draw a graph for each labor market, identifying the supply and demand curves and the initial equilibrium quantities and wages. In the graph of the unskilled labor market, show the effects of unskilled immigration on wages and employment. Which curve shifts? In the graph of the skilled labor market, show the effect of the increased supply of unskilled workers. Which curve shifts? In which direction will it shift if the two types of labor are relatively complementary, as argued by Ottaviano and Peri?
5. Are the wage results of the OTTA1 experiment consistent with those of your theoretical model? Why are the effects of immigration on skilled wages and capital rents positive when factors are relatively complementary?
6. Using your theoretical model describing the Ottaviano and Peri's argument, add the effects of capital stock growth. Which curve shifts in each graph? In which direction will they shift if all factors are relatively complementary, as argued by Ottaviano and Peri?
7. Are the wage results of the OTTA2 experiment consistent with those of your theoretical model? What happens in your model to the price of capital? Can you explain why?
8. Why does real GDP increase in all three scenarios? Why is real GDP growth higher in the BORJAS scenario compared to OTTA1?
9. What conclusions about modeling and the choice of elasticity parameters do you draw from your study of the two competing models of labor immigration?

Model Exercise 7: The Doha Development Agenda

Concepts: Import Tariffs; Export, Production, and Input Subsidies; SUBTOTAL and Welfare Decomposition

Background

Global trade negotiations under the General Agreement on Tariffs and Trade (GATT) – now named the World Trade Organization (WTO) – have been under way since shortly after the end of World War II. Consecutive rounds of trade negotiations have led to a reduction of global tariffs and other trade barriers, which has helped facilitate growth in global trade over the past six decades. Agriculture was generally excluded from the trade liberalization process until the Uruguay Round negotiations, which lasted from 1986 to 1994. These talks placed limits on agricultural trade barriers and production and export subsidies. The WTO-sponsored trade negotiations continued in the Doha Development Agenda Round, suspended for now, and so called because this round of negotiations was initiated in Doha, Qatar, in 2000 and is intended to benefit developing countries in particular.

There is much at stake for the global economy in completing the Doha Round, particularly for low-income countries, according to Kym Anderson and Will Martin, two prominent economists who studied the potential gains from the negotiations. Trade barriers are high: their study reports that high-income and low-income countries impose average tariffs of 16% and 18% tariff, respectively, on their agricultural imports (Table ME 7.1). Their average tariffs on manufactures average 1% and 8%, respectively. Agricultural subsidies continue to be provided, mostly by high-income countries.

To analyze the potential gains from eliminating these taxes and subsidies, Anderson and Martin used the World Bank LINKAGE model, a recursive dynamic global CGE model, to conduct their analysis (van der Mensbrugghe, 2005). The LINKAGE model is solved sequentially for a period of several years. The time path of solution values account for population growth over the time period and the role of savings and investment in capital stock and

Table ME 7.1. *World ad valorem Import Tariff Rates in Anderson and Martin (2005)*

	High-income Importers	Low-income Importers
Agriculture	16	18
Textiles	8	17
Other manufacturing	1	8
Total	3	10

Source: GTAP v6, 2001 database, as reported in Anderson and Martin.

Table ME 7.2. *Decomposition of the Welfare Effects from Full Trade Liberalization by Groups of Countries and Products (Total welfare effect = $U.S. 287 billion)*

	Agriculture	Textiles and Clothing	Other Manufactures	All Goods
High-income country policies	46	6	3	55
Low-income country policies	17	8	20	45
Total	63	14	23	100

Source: Anderson and Martin (2005).

productivity growth. Their version of the LINKAGE model uses the GTAP v6 database with a 2001 baseyear.

Anderson and Martin concluded that the full removal of all import tariffs, export subsidies, and domestic agricultural subsidies would boost global welfare by nearly $300 billion and by commodity (Table ME 7.2). They concluded that agriculture is the key to the success of the negotiations because global liberalization of agricultural tariffs and subsidies would contribute nearly two-thirds of the potential global welfare gains, mostly through developed countries' reforms. Low-income countries also have a role in the reform process. Their removal of nonagricultural import tariffs would account for most of their contribution to world welfare gains from Doha. Anderson and Martin argue that it is important that the Doha Round address the full range of policies and industries because that approach offers possibilities for trade-offs, such as concessions on agricultural policies in exchange for concessions on nonagricultural policies.

Experiment Design

In this exercise, you will replicate Anderson and Martin's analysis of a global elimination of tariffs and agricultural subsidies using your GTAP CGE model with the U.S. 3×3 database. Note some important differences between your model and theirs that make your results not directly comparable: (1) Their model uses a different, older version of the GTAP data, generally with higher tariffs and higher agricultural subsidy rates than in the v.8.1 database used in this exercise. (2) Their model, LINKAGE, is a recursive dynamic CGE model that allows economies to grow in size, implying that their welfare effects of the same proportionate size to the economy will be larger than welfare results from your static CGE model. (3) Their model contains more country and industry disaggregation than the toy 3×3 CGE model used in this exercise and there are high trade barriers within the large rest-of-world region in our model. (4) You remove *all* trade and production taxes and subsidies. Despite these model differences and caveats, this exercise remains useful for teaching you the modeling skills used to study multilateral trade liberalization, which has been an important application of CGE models.

In your experiment, you will use the GTAP SUBTOTAL facility (see directions in Model Exercise 5) to decompose global trade reform into four components:

1. U.S. Agricultural Policy Reform: eliminate U.S. agricultural production subsidies and tariffs and export subsidies on its agricultural trade with ROW.
2. U.S. Nonagricultural Policy Reform: eliminate U.S. tariffs and export subsidies on its MFG trade with ROW.
3. Rest-of-world (ROW) Agricultural Policy Reform: eliminate ROW agricultural production subsidies and tariffs and export subsidies on its global agricultural trade.
4. ROW Nonagricultural Policy Reform: eliminate ROW tariffs and export subsidies on its global MFG trade.

Instructions

1. Open the GTAP model with U.S. 3×3 database
   This step opens the version of the GTAP model that uses the U.S. 3×3 database. You created this version of the model in Model Exercise 1.
   - Open RunGTAP
   - On the top menu bar, choose “Version”
   - Change
   - Select US3×3
   - OK.
2. Prepare your model to run an experiment – check closure
   - Select the “Closure” page tab

     Check that no closure changes are lingering there. The closure should end with “Rest Endogenous.” If not, erase all text below that line.
3. Prepare your model to run an experiment – check shocks
   - Select “Shocks” page tab
   - Clear shock list
     This check ensures that there are no shocks lingering in your experiment file other than those you want to introduce.
4. Report selected base tax rates in Table ME 7.3.
   - Select “View” from the menu bar
   - Select “Base data” from the drop-down menu
   - Select “Tax rates” from the drop-down menu
     For each tax, select appropriate set elements to display in the upper right corner. For export taxes and import tariffs, report rates on U.S. and ROW exports to and imports from each other. Note the taxes and tariffs on ROW trade with ROW.

Table ME 7.3. *Base Tax Rates in U.S. 3×3 Model*

	United States			Rest-of-World		
Tax Type	Agr.	Mfg.	Services	Agr.	Mfg.	Services
Subsidies on domestic intermediate inputs used in agricultural production (rTFD)						
Subsidies on imported intermediate inputs used in agricultural production (rTFI)						
Export subsidies (rTXS)						
Import tariffs (rTMS)						

Source: GTAP v.8.1.

5. Define the first part of the experiment: U.S. Agricultural Policy Reform
   - Select the “Shocks” page tab
   - Set each of the following variables to a zero target rate (See directions on defining experiments in Model Exercise 3):

     tfd(tax on domestic intermediate inputs):
     elements All TRAD_COMM, “AGR”, “USA”
     tfm(tax on imported intermediate inputs):
     elements All TRAD_COMM, “AGR”, “USA”
     tms(import tariff): elements “AGR”, “ROW,” “USA”
     txs(export tax): elements: “AGR”, “USA,” “ROW”

6. Define these shocks as the subtotal “US Ag Policy Reform” following the directions on defining subtotals in Model Exercise 5. Be careful to select the elements for each variable on the SubTotals page to match the set elements on the shocks page.
7. Define the second part of the experiment: U.S. Nonagricultural Policy Reform
   - Set each of the variables listed below to a zero target rate:

     tms(import tariff): elements(“MFG”, “ROW”, “USA”)
     txs(export tax): elements(“MFG”, “USA”, “ROW”)
     Because tariffs and export taxes on trade in services are zero in the GTAP database, we do not need to remove them in our experiment.

8. Define the two shocks in the aforementioned step as the subtotal “US NonAg Policy Reform.”
9. Define the third part of the experiment: Rest-of-World Agricultural Policy Reform
   - Set each of the following variables to a zero target rate:

     tfd(tax on domestic intermediate inputs):
     elements All TRAD_COMM, “AGR”, “ROW”
     tfm(tax on imported intermediate inputs):
     elements All TRAD_COMM, “AGR”, “ROW”

- Set each of the variables listed below to a zero target rate:

  tms(import tariff): elements "AGR", "USA", "ROW"
  txs(export taxes): elements: "AGR", "ROW", All REG

10. Define these shocks as the subtotal "ROW Ag Policy Reform"
11. Define the fourth part of the experiment: ROW Nonagricultural Policy Reform
    - Set each of the following variables to a zero target rate:

      tms(import tariff): elements("MFG", All REG, "ROW")
      txs(export taxes): elements("MFG", "ROW", All REG)
      Because tariffs and taxes on trade in services are zero in the GTAP database, we do not need to remove them in our experiment.

12. Define these shocks as the subtotal "ROW NonAg Policy Reform."
13. Check that your shock page looks like Figure ME 7.1.
14. Save the experiment file
    - Select the "Solve" page tab
    - Check that the solution method is Gragg 2-4-6. If it is not, click on "Change," select Gragg from the box and then click on "OK."
    - Check that the parameter file is "Default". If it is not, click on "Change," select default.prm from the box and click OK.
    - Click on "Save experiment," name the shock DOHA, and describe it as Doha Development Agenda.

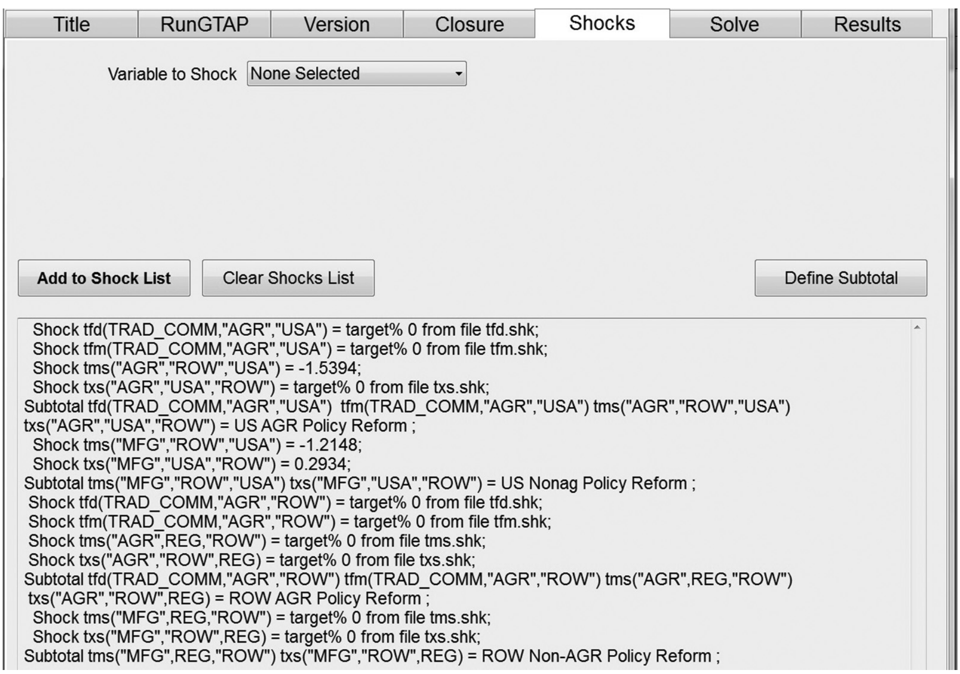


Figure ME 7.1. Shocks page for Doha Development Agenda experiment.

15. Solve the model
    - Select "Solve" page tab
    - Save experiment
    - Name the experiment "Doha"
    - OK
    - Solve
    - OK
    - OK.
16. After running the experiment, check the updated tax rates. For example, check that the input subsidies or taxes used by the agricultural sectors in the United States and rest-of-world are now zero
    - Select "View" from the menu bar
    - Updated data (from the drop-down menu)
    - Tax rates (from the drop-down menu)
    - rTFD – the *ad valorem* tax rate on firms' domestic purchases
    - Select set elements to display (in the upper right corner of the tax display page):

      ALL TRAD_COMM, AGR, ALL REG. All should have a value of zero.

    - Select and view each of the taxes that you have changed in this experiment.
17. From the results page, report model results for the equivalent variation welfare effect, EV, in Table ME 7.4.
18. Report the decomposition of the total welfare effect in Table ME 7.5.
    - Select "View" from the menu bar
    - Select "Updated data" from the drop-down menu
    - Select "Welfare decomposition"
    - Click on "EV decomposition summary" (in row 1)
19. Report the decomposition of the import tax welfare effect in Table ME 7.6:

    Trade Tax Effect: Explanatory Factors
    –Set toggles to
    SUM TRADE|AllREG|AllREG|Welcnt|Import

Table ME 7.4. *Welfare Effects of Trade Liberalization by Region and by Policy, $U.S. Millions*

Total	U.S. Agricultural Policy Reform	U.S. Nonagricultural Policy Reform	Rest-of-World Agricultural Policy Reform	Rest-of-World Nonagricultural Policy Reform
United States				
ROW				

Note: Welfare is an equivalent variation measure.
Source: GTAP model, GTAP v.8.1 U.S. 3×3 database.

Table ME 7.5. *Decomposition of the Total Welfare Effect, $U.S. Millions*

Total	Allocative Efficiency	Terms of Trade in Goods and Services	Terms of Trade in Savings-Investment
United States			
ROW			
World			

Note: Welfare is an equivalent variation measure.
Source: GTAP model, GTAP v.8.1 U.S. 3×3 database.

Interpret Model Results

1. Is the total world welfare effect of global policy reforms positive or negative? Explain what a change in the equivalent variation measure of welfare means.
2. Which elements of the global reform, in Table ME 7.4 contribute most to increasing or decreasing global welfare? Based on these findings, do you agree with the Anderson and Martin's conclusion that agricultural reforms will deliver most of the potential benefits of a global trade reform? Compare your initial import tariff rates with those of Anderson and Martin. How do you think that differences in initial tax rates influence model results?
3. Comment on the welfare gains to ROW from ROW non-AGR reform, in Table ME 7.6. Can you explain these based on the initial import tariffs in your model? How important is a review of initial tax before undertaking this analysis?
4. The allocative efficiency effect measures the efficiency gains to each economy when distorting taxes are reduced or removed. Based on Table ME 7.5, how important are these efficiency gains to both regions?
5. What does the terms of trade effect measure? How important is this effect in your model results? Explain why the terms of trade gains and losses to each region offset each other in your 3×3 model.
6. Which elasticity parameter in your CGE model most directly influences the terms of trade results in your model? Explain why.
7. How does your total world welfare result compare with that of Anderson and Martin? What are the differences between your CGE model and theirs that might explain some of the differences in your results?

Table ME 7.6. *Decomposition of the Import Tax Welfare Effect*

	U.S.	Rest-of-World
U.S.		
Rest-of-World		
Total		

Source: GTAP model, GTAP v.8.1 U.S. 3×3 database.

Model Exercise 8: The Marginal Welfare Burden of the U.S. Tax System

Concepts: Taxation, Direct, Excess, and Marginal Welfare Burden of Taxes, Welfare Decomposition, Systematic Sensitivity Analysis

Background

The U.S. tax system was the subject of some of the earliest applications of CGE models. An influential contributor to this body of research was the economist team of Charles Ballard, John Shoven, and John Whalley. They developed a recursive dynamic CGE model that supported several analyses of U.S. taxes, including Ballard, Shoven, and Whalley (1985). Their CGE model of the United States was based on a 1973 database with nineteen industries, twelve household types and eight types of taxes. Their model solved first for a baseline time path of the economy's growth. Their experiments then introduced changes in U.S. tax rates. The results of their model experiments plotted alternative time paths of U.S. economic growth, with and without the tax changes.

In their 1985 study, the team used their CGE model to analyze the combined marginal excess burden – the deadweight efficiency losses – of all taxes in the U.S. economy. The marginal tax rates in their model, reported as the average across industries and commodities, are presented in Table ME 8.1. Their tax rates are reported as the rate paid on net-of-tax income or net-of-tax expenditure. For example, if the tax paid on $1 of dividend income was 50 cents, then the individual would retain 50 cents in net-of-tax income. In this case, the tax rate would be 100% of net income (which is close to the rate of .97 reported in Ballard et al.'s model).

Their experiments were a 1% increase in every tax rate in the U.S. economy simultaneously and a 1% increase in each tax rate at a time. In this dynamic model, tax changes influenced households' savings rates and therefore the accumulation of capital and investment in the economy. Tax changes

Table ME 8.1. *Level and Dispersion of Tax Rates in the Ballard, Shoven, and Whalley Model*

	Average Marginal Tax Rates
Capital and property taxes	.97
Labor (factor use) taxes	.101
Consumer sales taxes	.067
Output and excise taxes	.008
Motor vehicle taxes	.052
Personal income taxes	.239

Source: Ballard, Shoven, and Whalley, 1985.

Table ME 8.2. *Marginal Excess Burden per Additional Dollar of Revenue for U.S. Taxes*

	Saving Elasticity		
Labor supply elasticity	0.0	0.4	0.8
0.0	.170	.206	.238
0.15	.274	.332	.383
0.30	.391	.477	.559

Source: Ballard, Shoven, and Whalley, 1985.

also influenced households' decision about how many hours to work. And, as in our standard, static CGE model, taxes led consumers and producers to change the quantities they produced and consumed as taxes changed relative prices of goods and services. Together, changes in investment and the supply of labor, and resource reallocation, altered the growth path of the economy. The authors also explored the sensitivity of their results to alternative elasticity parameter values for labor supply and household savings.

The team found that, depending on the elasticities, the marginal excess burden of the U.S. tax system ranged between 17 cents and 56 cents per dollar of additional tax revenue (Table ME 8.2). This meant that government projects to be funded by the tax increase would have had to yield benefits at least 17% greater than the amount of the additional tax revenue. After changing one tax at a time, they concluded that the consumer sales tax was the most distorting of the U.S. taxes (Table ME 8.3).

Based on their findings, Ballard and colleagues argued that plans for public spending on projects or on income transfers, such as welfare payments, needed to take into account the efficiency losses incurred by raising

Table ME 8.3. *Marginal Excess Burden per Dollar of Additional Revenue from Specific Portions of the Tax System*

Uncompensated saving elasticity	0.0	0.4	0.0	0.4
Uncompensated labor supply elasticity	0.0	0.0	.15	.15
All taxes	.17	.206	.274	.332
Capital taxes	.181	.379	.217	.463
Labor taxes	.121	.112	.234	.230
Consumer sales tax	.256	.251	.384	.388
Sales tax on commodities other than alcohol, tobacco, gas,	.035	.026	.119	.115
Income taxes	.163	.179	.282	.314
Production taxes	.147	.163	.248	.279

Source: Ballard, Shoven, and Whalley, 1985.

additional tax revenue. They also argued that the large marginal excess burden of additional taxes conversely offered opportunities, because there could be large marginal efficiency gains from small reforms in taxes.

Experiment Design

In this exercise, you will replicate the Ballard, Shoven, and Whalley (1985) study using the GTAP CGE model with the U.S. 3×3 database. There are differences between your models, which are likely to lead to differences in your results. Your model has a 2004 database, and you will be asked to see how its tax rates differ from the 1973 rates described in Ballard et al.'s analysis. Note that almost all tax rates reported in your CGE model are calculated gross of tax, so they will be lower than those of Ballard et al. That is, if the tax paid on $1 of dividend income were 50 cents, then the tax rate would be 50% of gross income. Your model is aggregated to three industries and a single household so there is less scope for distortions in the relative prices of goods, and the efficiency losses from tax increases could therefore be smaller in your model. Also, Ballard and colleagues used a recursive dynamic CGE model while yours is a static CGE model with a fixed supply of capital and labor. Therefore, by assumption, your model will not account for taxes' effects on the supply of savings and investment. In addition, income taxes influence labor supply in their model, whereas the labor supply is fixed in your model. On the other hand, your model has important capabilities that theirs did not. Because it is a multi-country model, your measure of the welfare effects of tax reform includes not only the excess burden of taxes but also their terms-of-trade effects. Also, the welfare decomposition utility of the GTAP model allows you to decompose the contributions of each type of tax to the total excess burden, instead of running separate experiments. Finally, the systematic sensitivity analysis utility allows you to describe confidence intervals around your results as you test for sensitivity to one parameter, the factor substitution elasticity.

In this exercise, you will:

1. Change selected elasticity parameters.
2. Define and run an experiment that increases all U.S. taxes by 1%.
3. Use the GTAP welfare decomposition facility to decompose the contribution of each tax to the excess burden of the tax increase.
4. Carry out a systematic analysis of the sensitivity of welfare results to alternative assumptions about the factor substitution elasticity.

Instructions

1. Open GTAP model with U.S. 3×3 database
   This step opens the version of the GTAP model that uses the U.S. 3×3 database. You created this version of the model in exercise 1.

- Open RUNGTAP
- On the top menu bar, choose "Version"
- Change
- Select "US3×3"
- OK.

2. Prepare your model to run an experiment – check closure
   - Select the "Closure" page tab

   Check that no closure changes are lingering there. The closure should end with "Rest Endogenous." If not, erase all text below that line.
3. Prepare your model to run an experiment – check shocks
   - Select "Shocks" page tab
   - Clear shock list

   This check ensures that there are no shocks lingering in your experiment file other than those you want to introduce.
4. Change these elasticity parameters and save a new parameter file (see instructions in Model Exercise 3)
   - ESUBVA (factor substitution elasticity) = 2 in all production activities
   - ESUBD (demand substitution between imported and domestic) = 6 for all commodities
   - ESUBM (demand substitution among imported varieties) = 10 for all commodities
   - Save the new parameter file and name it "Ballard.prm."
5. Define your experiment
   - Select, sequentially, each of these tax rates: *tf*, *tfd*, *tfm*, *tgd*, *tgm*, *to*, *tpd and tpm*
   - Select all elements for each tax for the U.S. region only
   - Define shock value for each tax as 1
   - Define type of shock as "% change rate"
   - Select import tariffs by the USA on imports from ROW – tms(All TRAD_COMM,"ROW", "USA")
   - Define shock value for import tariffs as 1 and type as "% change rate"
   - Select export taxes by the USA on exports to ROW – txs(All TRAD_COMM,"USA","ROW")
   - Define shock value for export taxes as 1 and type as "% change rate."
6. Your experiment page should look like Figure ME 8.1.
7. Save the experiment file
   - Select the "Solve" page tab
   - Check that the solution method is Gragg 2-4-6. If it is not, click on "Change," select Gragg from the box and then click on "OK."
   - Change your parameter file by clicking on "Change" next to "Parameter file: default," and select your new parameter file name, Ballard.prm
   - OK (this closes your parameter file dialogue box)
   - Click on "Save experiment," name the shock "Ballard," and describe it as 1% increase in all taxes.

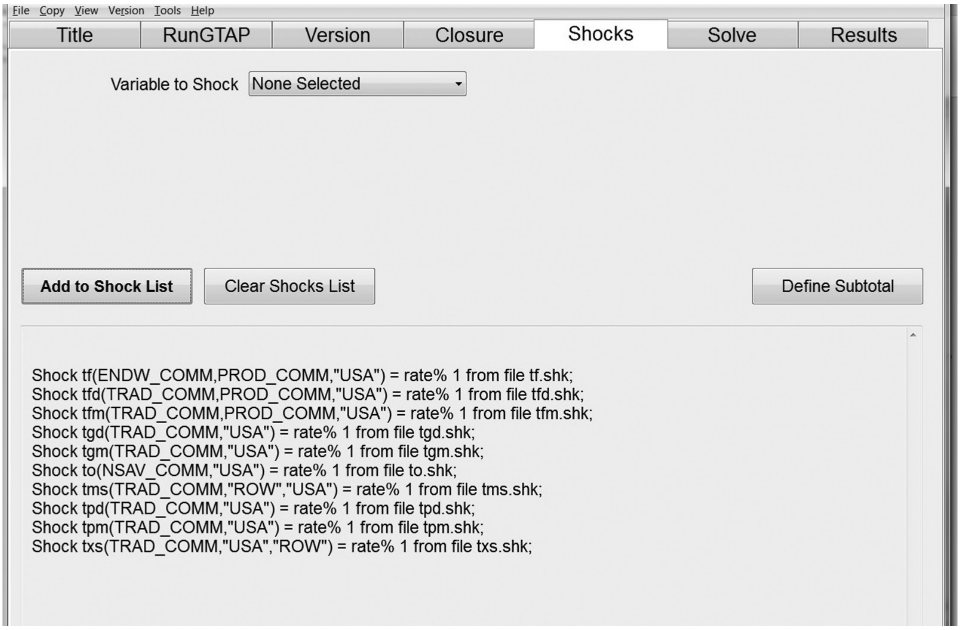


Figure ME 8.1. Shocks page in marginal welfare burden experiment.

8. Solve the model
   - Click on Solve
   - OK
   - OK.
9. Report results from the welfare decomposition utility in Tables ME 8.4 and ME 8.5
   - Select "View" from the menu bar
   - Select "Updated data" from the drop-down menu
   - Select "Welfare decomposition" from the drop-down menu
   - Select "EV Decomposition Summary" (row 1) for Table ME 8.4 results
   - Return to main menu of decomposition by double-clicking on data anywhere in the matrix
   - Select "Allocative efficiency by tax type" (row 3) for Table ME 8.5 results.

Table ME 8.4. *Welfare Effects of a 1% Increase in U.S. Taxes ($U.S. Million)*

Allocative efficiency	Endowment	Technology	Population	Terms of trade in goods and services	Terms of trade in investment-savings	Preference	Total welfare cost	Change in government tax revenue	Welfare cost (cents) per dollar of revere

Source: GTAP model, U.S. 3×3 v.8.1 U.S. 3×3 database.

Table ME 8.5. *Welfare Decomposition of the Allocative Efficiency Effect ($U.S. Million)*

Tax Type	Welfare Cost
Factor tax (pfactax)	
Production tax (prodtax)	
Input tax (inputtax – *tfd* + *tfm*)	
Private consumption tax (contax – *tpd* + *tpm*)	
Government tax (govtax – *tgd* + *tgm*)	
Export tax (xtax)	
Import tax (mtax)	
Total	

Source: GTAP model, GTAP v.8.1 U.S. 3×3 database. Experiment is a 1% increase in all U.S. taxes.

10. Calculate the change in total government tax revenue by comparing the pre- and post-experiment tax revenues. Find the base tax revenue value by selecting from the top menu bar:
    - Select "View" from the menu bar
    - Base data
    - GtapView Output
    - GDPSCR (GDP from the income sources side)
    - Report NETAXES (tax revenue) for the U.S. in "a."
    - Report updated tax revenue data in "b", by repeating these steps but choosing "Updated data" instead of "base data"
    - Calculate the change in tax revenue by subtracting the old revenue from the new revenue. Report this in "c" and in the second-to-last column of table 8.4.
      a. Base government tax revenue ($ U.S. millions) ____________________
      b. Updated government tax revenue ($ U.S. million) ____________________
      c. Change in government tax revenue ($ U.S. million) ____________________
11. Carry out a systematic sensitivity analysis (SSA) of model results to changes in the elasticity of factor substitution (ESUBVA) parameter. Follow the instructions in Model Exercise 3, and use the information below as your inputs to the SSA utility.
    - Parameter to vary: ESUBVA
    - Elements to vary: ALL PROD_COMM
    - Percent variation: 100 (the sensitivity analysis will vary the ESUBVA elasticity parameter value between close to zero and two times the base parameter value, or 4)
    - Type of variation: Percent (this is the default choice)
    - Type of distribution: triangular (it is similar to a bell curve distribution and is the default choice)

- Select add to list (this places your selected parameter into the list that will be varied in the SSA)
- OK
- OK (this accepts the default settings, including the Stroud quadrature)
- Save (this saves your solution files)
- OK
- Yes (this saves your two solution files)
- OK
- Name your two solution files or accept their default names.
- Open and view the files with the sensitivity analysis results.[3]

12. Report results from the ViewSol file for U.S. equivalent variation measure of welfare (EV):

    EV _________________
    Mean ________________
    Standard deviation _______

Interpret Model Results

1. Based on your results, what is the direct burden of the marginal tax increase? What is its excess burden (allocative inefficiency)?
2. Calculate the marginal welfare burden of the U.S. tax system
3. Total welfare cost/Change in government tax revenue $*$ 100 = Marginal welfare burden
4. Define the marginal welfare burden that you calculated in problem 2. Explain how you would use your answer to problem 2 to advise policy makers considering a U.S. tax increase to fund a government project.
5. According to results reported in Table ME 8.5, which tax has the largest marginal welfare effect? The smallest (excluding government tax)? Use data from the U.S. 3×3 structure table and your knowledge of the excess burden of taxes to comment on your result for the consumption tax.
6. How important are the terms of trade gain in goods and services in the welfare results? Explain what a change in this component of terms of trade means. Why is it included in the welfare measure?
7. How does your finding on the marginal welfare cost per dollar of marginal revenue compare with the findings of Ballard, Shoven, and Whalley? What are some of the differences between your CGE models that might account for differences in results?
8. View the initial tax rates in your model and compare them with those of Ballard, Shoven, and Whalley. Although your tax rate definition differs from that of

[3] Note that you must have a GEMPACK license to view the results. Temporary licenses are available for free from GEMPACK and the Centre of Policy Studies at Victoria University in Melbourne, Australia. Their Web site is www.copsmodels.com/gpeidl.htm

Ballard, Shoven, and Whalley, how do you think the differences in your data might account for different model results?

9. Using the results of the systematic sensitivity analysis on the elasticity of factor substitution (ESUBVA) and Chebyshev's theorem (see Model Exercise 3), define the range of value for the U.S. equivalent variation welfare effect in which you have 75% confidence and 95% confidence. Based on your sensitivity analysis of the elasticity, do you think that your equivalent variation welfare result is a robust finding?

Model Exercise 9: Climate Change – the World in 2050
Concepts: Baseline Scenario, Closure, Factor Productivity, Integrated Assessment

Background

The Fifth Assessment of the Intergovernmental Panel on Climate Change reports that the "(w)arming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased" (IPCC, 2013). Understanding the potentially enormous implications of climate change for humanity has united experts from both the physical and social sciences in increasingly integrated and collaborative research.

The integrated research process begins with global climate models (GCMs). GCMs utilize physical, chemical, and biological principles to simulate the interaction of the atmosphere, oceans, land surface, snow ice, and permafrost and their responses to rising levels of greenhouse gases. GCMs also take into account alternative projections of socioeconomic "pathways" that include population, income growth, energy use policies, and other variables that influence levels of greenhouse gas emissions. Using different combinations of socioeconomic pathways and assumed greenhouse gas emission levels, GCMs provide a range of projections for future changes in Earth's climate. Projected climate changes from GCM models are used as inputs into biophysical models. These models use mechanical or statistical methods to simulate the effects of projected climate change on biological and physical processes and systems such as crop yields, water supply, and human health and productivity. The projections from the biophysical models are then used as inputs into economic models, such as CGE models, to simulate economic responses to the impacts of climate change and to explore the effectiveness of alternative policies to either combat or adapt to it.

Informed and effective climate change policies crucially depend on the availability and credibility of sound economic analyses. Yet so far, a comparison of the results from economic models shows substantial differences in their projections of the effects of climate change on key economic variables (Nelson et al., 2014). To better understand why the models' results diverge, economists from leading research organizations around the world worked collaboratively to critically compare their research on economic responses to climate change in a project called the Agricultural Model Inter-Comparison Project (AgMIP) (Nelson et al., 2014). Nine models, including five CGE models, were included in AgMIP. The researchers' objective was to introduce a common set of climate change and crop yield inputs into their economic models, so that any divergences in economic responses could be understood in terms of differences in the structure and parameters of the economic models.

The economists began by agreeing on seven scenarios of the biophysical crop yield changes to be introduced as shocks into their models. The crop yield shocks were based on combinations of projections from two GCMs and five biophysical models. The GCMs' scenarios combined a representative (greenhouse) gas concentration pathway (RCP) of 8.5, which is the most extreme of the emissions scenarios, with the Shared Socioeconomic Pathway #2 (SSP2). The SSP2 describes a middling pathway of global socioeconomic development, with moderate achievements and challenges in achieving economic growth and development, maintaining the capacity of global institutions, and undertaking mitigation and adaptation to climate change. The resulting outcomes from the GCMs for climate conditions in 2050 were then introduced into five crop yield models to simulate the impacts of climate change (assuming no yield benefits from rising CO_2) for four crop groups and thirteen regions. The biophysical models predicted an average crop yield decline of 17% in 2050 across the scenarios, crops, and geographic regions.

The economists were asked to compare economic variables in 2050, with and without climate change. To develop the same 2050 baseline scenario, without climate change, they all used the same projections through 2050 for population and GDP growth from the SSP2 scenario, and adopted the same exogenous projections for growth in cropland area and yields, and endowments of labor and capital. Their counterfactual climate change experiment included the same growth projections as in the baseline scenario, with the addition of crop yield shocks from the biophysical models of climate change. A comparison of results between their baseline scenario and their counterfactual, climate-change experiment described the effects of climate change on economies in 2050. The differences in models' results largely stemmed from differences in their depiction of land use and yield responses, and in the propensity to trade.

All of the economic models describe producer and consumer responses to the decline in crop yields. The decrease in crop production causes prices to rise. Depending on the economic models' capabilities, producers respond to higher prices by intensifying their cultivation practices (and raising yields) and by expanding their cultivated area. These economic responses moderate the projected yield and production impacts from climate change that are estimated in the biophysical models. Consumers react to higher food prices by reducing the quantity of food demanded. Trade has a role in bridging supply and demand across regions.

A comparison of the models' results show that, on average, producers' compensating behaviors reduce the decline in mean crop yields from 17% to 11% and increase the crop land area by 11%, resulting in a mean decline in production across countries and commodities of only 2%. Food consumption declines only slightly, by 3% on average, despite an average increase in the producer prices of crops of 20%. The share of global trade in world food production increases by one percentage point, indicating that trade has a role as an adaptive mechanism. In general, models concur that a large part of the adjustment occurs in production and trade responses, although the sizes of these responses vary substantially across models. Consumption responses are relatively small and diverge little across models.

Experiment Design

In this model exercise, you are going to carry out an economic analysis of climate change that is part of an integrated modeling framework that links the impacts from global climate models, through biophysical crop models to an economic model. You will construct a baseline scenario and define a counterfactual experiment.

The baseline scenario describes the U.S. and ROW economies in 2050 with a constant, unchanged climate. To develop the baseline, you will supply your model with projected changes in values between 2007 and 2050 for five macroeconomic variables: real GDP, population, and supplies of land, labor and capital (Table ME 9.1). Following Nelson and colleagues, your baseline scenario will describe projected real GDP and population for 2010–2050 from the SSP2. Projections for labor and capital supply growth for 2010–2050 are from Fouré et al. (2012). Because your model has a 2007 base year, we add historical growth rates for 2007–2010 to the AgMIP projections to develop projections for 2007–2050. Projected growth in agricultural land area is drawn from Bruinsma (2011).

Table ME 9.1. *Projections for baseline scenario, 2007–2010*

	Real GDP (*qgdp*)	Population (*pop*)	Labor force (*qo*)	Physical capital (*qo*)	Arable land (*qo*)
United States	109.6	32.3	24.1	60.6	–0.93
Rest-of-world	284.5	37.3	38.4	213.1	4.4

Sources: Arable land projections for 2007–2050 are from Bruinsma (2011). Actual growth rates for 2007–2010 for other variables are from World Bank Development Indicators, except physical capital growth, which is estimated. Projected real GDP and population for 2010–2050 are from the SSP2 scenario, SSP Database v. 0.9.3 (2012). Projected labor force and physical capital growth for 2010–2050 are from Foure et al. (2012).

Real GDP is an endogenous variable in the GTAP model. To impose the projected real GDP, you must first change your model's closure by swapping real GDP for total output productivity, which is an exogenous variable. This closure swap creates a baseline scenario experiment that solves for the change in economy-wide productivity that is necessary to achieve the projected growth in real GDP, given the projected growth in factor supplies and population. You will then restore the original closure, making real GDP endogenous and productivity exogenous. You will add the solution values for productivity growth to your baseline shocks, turn off the exogenous GDP growth targets, and re-solve the baseline experiment. The results of this experiment are your baseline scenario for the world economy in 2050.

The counterfactual experiment describes the U.S. and ROW economies in 2050 with climate change. Your experiment will impose the same factor endowment and productivity projections as in the baseline, but also will include the effects of climate change on land supply and agricultural productivity. The differences in results between the baseline scenario and the climate change experiment describe the effects of climate change in 2050.

This exercise introduces you to the core elements of creating a baseline scenario and a counterfactual experiment. However, it is highly stylized, and there are important differences between your study and the AgMIP analyses. First, some AgMIP models assume an endogenous land supply, which allows crop area to expand as crop prices rise, and these area changes are not the same everywhere. Because your CGE model assumes a fixed land supply, you will impose the average, global 11% increase in agricultural area in 2050 reported by AgMIP models on both regions in your model. Also, some AgMIP models account for farmers' intensified management practices, which moderate the mean global crop yield decline of 17% projected in the crop models. Because your CGE model does not account for endogenous yield responses, your climate change experiment will impose the final mean yield change for crops of -11% in 2050 reported by AgMIP models. Third, the AgMIP models describe an exogenous productivity growth trend in agricultural yields, which you do not include in your analysis. Also, the US3×3 database has a single agricultural sector. Imposing the climate change experiment on total agriculture in each region, rather than on crops alone, may overstate the economy-wide impacts of the climate change shock. In addition, the rest-of-world is a highly aggregated single region, so that the role of trade in bridging matching changes in food supply and demand cannot be fully explored.

Instructions

1. Open the GTAP model with U.S. 3×3 database
   This step opens the version of the GTAP model that uses the U.S. 3×3 database. You created this version of the model in Modeling Exercise 1.

- Open RunGTAP
- On the top menu bar, choose "Version"
- Select "Change"
- Select US3×3
- OK.

2. Prepare your model to run an experiment – check closure
   - Select the "Closure" page tab

   Check that no closure changes are lingering there. The closure should end with "Rest Endogenous." If not, erase all text below that line.

3. Prepare your model to run an experiment – check shocks
   - Select "Shocks" page tab
   - Clear shock list

   This check ensures that there are no shocks lingering in your experiment other than those you want to introduce.

4. Change parameter values for income elasticity (INCPAR)
   Follow the instructions for changing and saving elasticity parameter values in Model Exercise 3 to change the income elasticity parameter (INCPAR) for AGR in all regions to 0.05 and save it as a new parameter file. This low income elasticity of demand better describes the long-run insensitivity of consumer demand for food as their incomes increase.
5. Select model solution method
   - Select "Solve" page tab
   - Click on "Change" (this button is to the upper right corner of page)
   - Select "Gragg"
   - Change the number of steps to 6-8-10 and set the number of subintervals to 10 (this breaks the large economic changes that occur over 2007–2050 into more and smaller shocks for which sequential linear solutions will be found)
   - OK (this saves your selected solution method).
6. Change model closure to swap real GDP with output productivity (aoreg) by region
   - Select closure tab from top menu
   - Below "Rest Endogenous" add:

   swap qgdp(reg) = aoreg(reg);

7. Develop the baseline scenario using macroeconomic projections in Table ME 9.1
   a. Develop real GDP shocks
      - Select the "Shocks" page tab
      - Select from the "Variable to Shock" drop-down menu: *qgdp*
      - Select from the "Elements to Shock" drop-down menu: USA
      - In "Percent Change Shock" box, enter: 109.6
      - Click on "Add to Shock list"

   b. Repeat these steps to define the real GDP shock in ROW, and the changes in both regions for population and endowments (*qo*) of land, labor and capital, and population.

Table ME 9.2. *Percent Changes in Productivity and Real GDP in Baseline Scenario, 2007–2050*

	U.S.	ROW
Total output productivity (*ao*) 1/		
Real GDP (*qgdp*)		

1/ Results for *aoreg* are reported on the Results page tab as "*ao*." Real GDP growth rates are solution values in the baseline scenario.
Source: GTAP CGE model, GTAP v8.8 US 3×3 database.

8. Solve the model
   - Select the "Solve" page tab
   - Click on "Save experiment," name it something like "BASE1" and describe it as "2010-2050 baseline with exogenous GDP"
   - Click on "Solve"
   - OK
   - OK
9. Report in Table ME 9.2 your results for productivity growth only (you will report changes in real GDP later).
   Select the Results page tab and open results for the productivity variable. It is described as variable *ao* on the results page. Notice that it is identical for all sectors. Report the productivity results to the 2nd decimal place.
10. Restore original model closure and rerun the baseline scenario
    In this step, you will remove your model swap on the model closure page; this makes real GDP endogenous and the *ao* productivity variable exogenous.
    - Select the "Closure" page tab
    - Erase the closure swap between qgdp and aoreg
    - Select the "Shocks" page tab
    - Erase the qgdp shocks that define the targeted gdp growth rates
    - Select from the shocks list "aoreg"
    - Define the aoreg shocks for U.S. and ROW using the values you reported in Table ME 9.2
    - Save your experiment, naming it "BASE2" and describing it as "2050 Baseline with Endogenous QGDP"
    - Solve the model
    - Select the "Results" page tab, open results for qgdp and report them in Table ME 9.2. Note that these GDP growth rates may vary slightly from the target growth rates. It is because the very large size of these shocks may affect model accuracy.
    - Select the "Results" page tab, and report in Table ME 9.3 the results for both countries in the "Without climate change" column.
11. Define the climate change experiment
    In this step, you will redefine the baseline experiment to include the projected crop area and yield shocks that result from climate change.

Table ME 9.3. *Economic Effects of Climate Change in 2050 (% changes 2007–2050)*

	United States			ROW		
	Without climate change	With climate change	Effect of climate change	Without climate change	With climate change	Effect of climate change
Real GDP (*qgdp*)						
Agricultural output (*qo*)						
Agricultural producer price (*ps*)						
Agricultural private consumption (*qpd*)						
Agricultural consumer price (*pp*)						
Agricultural exports (*qxw*)						
Agricultural imports (*qiw*)						
Import share of agricultural consumption (*qiw-qpd*)						
Export share of agricultural production (*qxw-qo*)						

Source: GTAP CGE model, GTAP v8.1 US 3×3 database.

a. Load the experiment “BASE2 - 2050 Baseline with Endogenous QGDP”
b. Impose climate shock – increase the land used in agriculture by 11%
   - Delete the qo”(LAND”) shocks defined in the baseline scenario
   - Calculate the net changes in agricultural land, including climate change, by adjusting projected exogenous increase in land area by the 11% increase due to climate change. For example, the net change in the U.S. land area = (–.93) + 11 = 10.07%
   - Select from the “Variable to shock” drop-down menu: *qo*
   - Select from the “Elements to shock” drop-down menu: Land
   - Select from the “Region” drop-down menu: USA
   - In the “% Change Shock” enter: 10.07
   - Click on “Add to Shock list”
   - Repeat to define the net change in agricultural land in ROW.
c. Impose climate shock – decrease agricultural yields by 11%
   - Select from the “Variable to shock” drop-down menu: *aoall*
   - Select from the “Elements to shock” drop-down menu: AGR and All REG
   - In the “% Change Shock” enter: −11
   - Click on “Add to Shock list

12. Solve the model
   - Select the “Solve” page tab
   - Click on “Save experiment,” name it CCEXP and describe it as “2010-50 with climate change”

- Click on "Solve"
- >OK
- >OK.

13. Report your results in Table ME 9.3 in the column titled "With climate change."
14. Calculate the effects of climate change in 2050

    Subtract data in the column "With climate change" from data in the column "Without climate change" and report it in the column "Effect of climate change."

Interpret Model Results

1. Explain the chain of models in your integrated economic assessment. What output is produced by each model and how is it used as an input into the next model in the integrated assessment?
2. Develop a theoretical model (as a graph of supply and demand in agriculture) to describe the effects of the climate change shocks on the U.S. agricultural sector. Are your model results for agricultural production, private consumption (demand), and producer and consumer prices consistent with that model?
3. How did you change the closure when setting up your baseline scenario, and why? Why do you use the original closure in both your baseline scenario and in your climate change experiment?
4. What are the adjustments to climate change that you are assuming (that is, are exogenous) in your climate change experiment? What adjustments are endogenous?
5. What are the main sources of adjustment to climate change in your model? How do your results compare with those of the AgMIP findings that production and trade are key adjustment mechanisms?
6. How has the trade dependency of agricultural production and consumption changed? What do these results suggest to you regarding a trade policy strategy for the two economies?
7. What elasticity parameters or shocks do you think might be important to examine further in a sensitivity analysis? Why?
8. A recent study of the effects of higher temperatures on humans projects a change in labor productivity by 2055 of -.73% in the United States, and a global average productivity loss of about 2% (UNDP, 2016). Extend your climate change analysis to include these labor productivity shocks. Shock the variable afeall and define a reduction in labor productivity in all sectors in the U.S. by -.73% and in the rest of world by -2%. Describe your key findings.

Model Exercise 10: Successful Quitters – The Economic Effects of Growing Antismoking Attitudes

Concepts: Baseline Scenario, Changing Consumer Preferences, Macroeconomic Projections, Systematic Sensitivity Analysis

Background

Cigarette smoking can have serious health consequences, not only for smokers but also for those around them who breathe in their secondhand smoke. As more becomes known about the negative effects of cigarettes on health, consumer attitudes toward smoking – at least in some countries – have begun to change. The days of glamorous movie stars puffing on cigarettes on the silver screen are long gone. Instead, smoking is increasingly viewed unfavorably, and there is growing social acceptance of (and even demands for) bans on smoking in public places such as offices, restaurants, and airplanes.

Globally, cigarette consumption has declined since the 1990s, but this broad trend masks differences among categories of countries, according to Goel and Nelson (2004). Their international comparison of smoking trends found that declining cigarette consumption is correlated with a country's stage of development. Approximately one-half of the high and upper middle-income countries in their data set witnessed a decline in per capita cigarette consumption in excess of 20% since the 1990s. In contrast, cigarette consumption actually increased over that period in half of the low-income countries in their study. Goel and Nelson suggest a number of reasons why a country's stage of development may affect its national smoking habits. For example, wealthier nations have better resources to monitor and control tobacco use, and a more educated population might be more aware of the health risks posed by smoking. But the researchers also found many exceptions to this broad relationship between smoking and income. These variations probably also reflect the significant differences across countries in antismoking policies, such as taxes and regulations on trade and advertising.

Changes in consumer attitudes toward particular products can have important consequences for an industry. Sometimes changing attitudes lead to a boom in consumer demand, such as the new popularity of organic foods. In other cases, consumers develop aversions, such as the avoidance of conflict diamonds because their proceeds may fund wars. When the affected industries are important in a national economy, changes in consumer preferences can also have significant economy-wide effects.

Experiment Design

In this exercise, you will create a 3×3 database with a tobacco sector, to explore the economy-wide effects of changing consumer attitudes about smoking as incomes grow. You will start by studying your database to understand the role of tobacco in the U.S. and ROW economies.

Next, you will create a baseline scenario that describes long-run growth in the U.S. and ROW economies in the absence of a change in consumer preferences. Your baseline experiment will impose macroprojections for factor endowment and productivity growth over the 2007–2025 time period, following the methodology used by Arndt et al. (1997). Imposing macroprojections for 2007–2025 as a model shock describes a new equilibrium in 2025, with higher levels of population, capital, labor, and productivity. Your model solves for a microeconomic structure that is consistent with the new macroeconomic aggregates. For example, if the economy's total capital stock (a macroeconomic parameter) is assumed to increase by 10%, your model results describe the microeconomic changes in capital stock in each industry, industry output, commodity demand, and so forth that are consistent with a more capital-rich endowment.

Next, you will rerun the same experiment but reduce the income elasticity of demand in the rest of the world to describe the increased aversion of its consumers to tobacco products as their incomes grow. You describe this change in preferences in the GTAP model by reducing the value of the INCPAR parameter, which is similar to, but not exactly the same as, the income elasticity of demand. When this parameter is reduced, any given percentage increase in income will result in a smaller increase in consumers' tobacco purchases. You will reduce INCPAR to a value that reduces the quantity of consumer demand for tobacco in ROW in 2025 by about 10% compared to current preferences. This is about one-half of the quantity reduction experienced in developed countries during the 1990s.

You will select and compare results of the two experiments to answer the question: How will a change in consumer attitudes toward smoking affect countries' tobacco industries and their national economies as global incomes rise over the next decade? Given the uncertainty about the extent to which income growth may change consumer preferences, you will use the systematic sensitivity analysis utility with respect to the income parameter, INCPAR. This will allow you to describe model outcomes in terms of means, distributions, and confidence intervals.

Table ME 10.1 presents macroprojections for 2007–2025, drawn from multiple sources, that describe the cumulative growth rates that you will use for your baseline scenario experiment. The growth rates for 2007–2015 are actual historical rates and those for 2015–2025 are projected. Notice that the projections describe growth rates in real GDP. You will solve for the projected change in factor productivity implied by this level of real GDP growth by changing the model closure to fix real GDP and make productivity endogenous.

Table ME 10.1. *Projected Cumulative Growth Rates for Baseline Scenario, 2007–2025*

	Real GDP (*qgdp*)	Population (*pop*)	Labor force (*qo*)	Physical capital (*qo*)	Land (*qo*)
United States	45.0	13.9	7.8	16.0	–0.5
Rest-of-world	67.7	20.6	23.2	42.0	2.0

Sources: Actual and projected growth rates for real GDP and population are from U.S. Department of Agriculture (2015). U.S. labor growth rates for 2007–2022 are from the U.S. Bureau of Labor Statistics (2015). Capital and ROW labor projections are from Foure et al. (2012).

There are some limitations to our analysis. One is our simplifying assumption that "ROW" preferences describe developing countries. Our 3×3 aggregation scheme includes all countries except the United States, so some countries included in ROW have already experienced changes in attitudes about smoking. A second limitation is that the GTAP database combines beverages with tobacco, so demand and production of "tobacco" in our model is not completely accurate. Third, it is difficult to predict how economic growth will affect consumer preferences because these are not always fully explained by economic forces. The systematic sensitivity analysis with respect to the INCPAR parameter allows us to characterize the preference change as a range instead of a specific value, and to present our model results in terms of means and distributions.

Instructions

1. Open GTAPAgg81y07
2. From the menu bar, select "Read Aggregation Scheme from File."
   - Select the U.S. 3×3 aggregation file (This is a shortcut to creating a new 3×3 model, because regions and factors in your database for this exercise remain the same as in the U.S. 3×3 database. If you did not create a U.S. 3×3 model, follow instructions in Model Exercise 1 to create a U.S. 3×3 database, and replicate the steps for "Define the country aggregation" and "Define the factor aggregation.")
3. Define the sector aggregation.
   - From the menu bar, select "View/change sectoral aggregation."
   - Create these three sectors:

TOB – "tobacco"	comprised of sector 26 b_t
AGRMFG – "AGR and MFG"	comprised of sectors 1–25, 27–42
SER – "Services"	comprised of 43–57

- OK (this saves your new sector aggregation)

4. Save your data aggregation file
   - From the menu bar, select on "Save aggregation scheme to file." (GTAP provides a default name, "gtpXX.agg," which you can change to something descriptive, like "TOBAC.agg.")
   - Save this aggregation file in the folder that you created for your research project.
5. Create the aggregated database
   - From the menu bar, select "Create aggregated database." This creates a zip file with the aggregated database. Give it the same name as your aggregation scheme, for example TOBAC.zip, and save it in your project folder.
   Your database is now saved in zipped Header Array (HAR) files that are ready to use in your CGE model.
6. Explore the SAM to learn about the role of the tobacco sector in the GDP of each economy
   - Still in GTAPAgg81y07, click on "View output files" in the menu bar
   - Select GTAPSam.har
   - Select "ASAM" (the top row)
   - On the upper right side, choose these set elements to display the ROW SAM:

     ALL SAMAC ALL SAMAC ROW

     Calculate the share of tobacco's value added in GDP, and report it in Table ME 10.2.It may be useful to first export the SAM from the HAR file to Excel, following instructions in Model Exercise 3. You can use Table 5.1 as a guide to calculate value added in tobacco. Use the directions in step 10 of Model Exercise 8 to find the initial value of GDP.

Table ME 10.2. *Share of Tobacco Value Added in GDP, 2007*

	USA	ROW
Percent share of tobacco in GDP		

Source: GTAP v.8.1 3×3 tobacco model database.

7. Repeat these steps to calculate and report the share of tobacco in activity output in the United States, after changing the set elements to display to:

   ALLSAMAC ALLSAMAC USA

8. Create a GTAP model version for the antismoking exercise following the instructions in Model Exercise 1. Give your model version the same name as your aggregation scheme and database, TOBAC.
9. The GTAP model will run a consistency check and a test simulation. It may fail if you are using the uncondensed version of the GTAP model. If so, click on tools on the menu bar, and select "Run test simulation" from the drop-down box, and it will again run a test simulation.
10. Report your model's base parameter values for INCPAR in Table ME 10.3.

Table ME 10.3. *Base and Updated INCPAR Parameter Values*

	Base Parameter Values		Updated Parameter Values
	USA	ROW	ROW only
Tobacco			0.1
Agr/Mfg			*No change*
Services			*No change*

Source: GTAP model and GTAP v.8.1 3×3 tobacco model database.

11. Report your model's base private household consumption shares in Table ME 10.4

 To view budget share data:

- Select "View" from the menu bar
- Base data
- Updated GTAPView output
- Double-click on "Cost Structure of Consumption," or NPVA
- Click on the menu box on the upper left hand corner of the page that says "None," and select "COL" from the drop-down menu. The "Col" view calculates each cell as a ratio of the column total. In this case, the matrix displays budget shares of each commodity in total private household spending. Report your results to three decimal places.

Table ME 10.4. *Private Household Budget Shares Under Alternative Scenarios*

	Base		Income Growth		Income Growth with Row No-Smoking Preferences	
	USA	ROW	USA	ROW	USA	ROW
Tobacco						
Agr./Mfg.						
Services						
Total						

Source: GTAP model and GTAP v.8.1 3×3 tobacco model database.

12. Prepare your model to run an experiment – check closure
    - Select the "Closure" page tab

      Check that no closure changes are lingering there. The closure should end with "Rest Endogenous." If not, erase all text below that line.
13. Prepare your model to run an experiment – check shocks
    - Select "Shocks" page tab
    - Clear shock list

      This check ensures that there are no shocks lingering in your experiment file other than those you want to introduce.

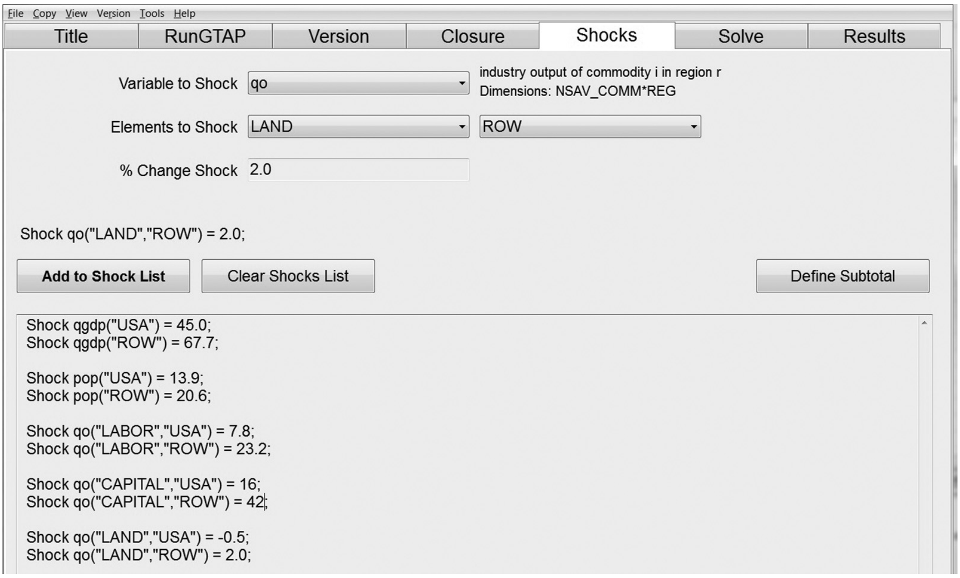


Figure ME 10.1. Shock page for the smoking preference experiment.

14. Define the baseline scenario
    - Select "Closure" page tab
    - Make real GDP (*qgdp*) exogenous and total factor productivity (*avareg*) endogenous by adding this line after the "Rest endogenous;" line of code: swap qgdp(REG) = avareg(REG);
    - Select "Shocks" page tab
    - Using the values in Table ME 10.1, define the shock for each of these parameters, for each region:

      Real GDP: *qgdp*
      Population: *pop*
      Factor endowments: *qo*("LABOR", r,)

    Your shocks page should look like Figure ME 10.1.
15. Save the experiment file
    - Select the "Solve" page tab
    - Check that the solution method is Gragg 2-4-6. If it is not, click on "Change," select Gragg from the box and then click on "OK"
    - Check that the parameter file is "Default". If it is not, click on "Change," select default.prm from the box and click OK.
    - Click on "Save experiment," name the shock BASELINE, and describe it as "2007-2025 baseline with default tobacco consumption."
16. Solve the model
    - Click on "Solve"
    - OK
    - OK.

Table ME 10.5. *Change in Rest-of-World Household Budget Shares (% change from base)*

	Income Growth with No Preference Change	Income Growth with Anti-smoking Preference
Tobacco		
Agr./Mfg.		
Services		

Source: GTAP model and GTAP v.8.1 3×3 tobacco model database.

17. Report updated private consumption budget shares in Tables ME 10.4 and ME 10.5
    - To view new budget shares, follow the directions in Step 11, except select "Updated data." Report the new budget shares in Table ME 10.4.
    - Calculate the percentage change in ROW's budget shares and report the change in Table ME 10.5.
18. Report model results for output changes in Table ME 10.6
19. Change consumer preferences for tobacco in ROW by changing the value of INCPAR. (For detailed instructions on changing an elasticity parameter and saving a new parameter file, see Model Exercise 3.)
    - Change INCPAR for tobacco in ROW to 0.1
    - Save the new parameter file as TOBAC.prm.
20. Solve the model
    - Select the "Solve" page tab
    - Check that the solution method is Gragg 2-4-6. If it is not, click on "Change," select Gragg from the box and then click on "OK"
    - Change the parameter file to "TOBAC"
    - Click on "Save experiment," name the shock AntiTOB, and describe it as "2007-2025 baseline with tobacco aversion"
    - Click on "Solve"
    - OK
    - OK
    - Report model results in Tables ME 10.4, ME 10.5, and ME 10.6.

Table ME 10.6. *Industry Output with and Without Changes in ROW Smoking Preferences (% change from base)*

	Income Growth		Income Growth with no-smoking Preferences	
	USA	ROW	USA	ROW
Tobacco				
Agr/Mfg				
Services				

Source: GTAP model and v.8.1 3×3 tobacco model database.

Table ME 10.7. *Systematic Sensitivity Analysis of Preference Changes on Tobacco Quantities in the Rest-of-World*

	Model Result	Mean	Standard Deviation	95% Confidence Interval	
				Upper	Lower
Production (*qo*)					
Private consumption (*qp*)					

Source: GTAP model and GTAP v.8.1 3×3 tobacco model database.

21. Carry out a systematic sensitivity analysis (SSA) of the degree of change in ROW attitudes about smoking as incomes grow (INCPAR). Follow the instructions in Model Exercise 3, and use the information below as your inputs to the SSA utility.
    - Parameter to vary: INCPAR of TOBAC in ROW
    - Percent variation: 100% (between close to zero and 0.8.)
    - Type of variation: Percent (this is the default choice)
    - Type of distribution: triangular (it is similar to a bell curve distribution and is the default choice).
22. In Table ME 10.7, report the mean and standard deviation results for two variables: tobacco output, *qo*, in ROW and quantity of consumer demand, *qp*, for tobacco in ROW. Calculate the 95% confidence interval for both results, using Chebychev's theorem (see Text Box ME 3.1).

Interpret Model Results

1. Provide an intuitive explanation of the INCPAR parameter and explain how the reduction in the value of INCPAR will affect ROW consumer demand as income grows.
2. Compare the base values for ROW's INCPARs for all three goods. Given these parameter values, how do you anticipate that growth in income will affect their relative budget shares in your base model scenario (with no preference change)? Are these expectations consistent with your model results?
3. Given the INCPAR parameters in the base model, how do you expect that income growth will affect industry structure? Are your results consistent with this expectation?
4. Develop your predictions for model results by drawing a graph that describes the market for tobacco in the ROW region. To keep it simple, ignore the effects of long-term economic growth on production.
   a. Draw a graph of the supply and demand for tobacco. Label the axes and curves, and label the initial market equilibrium, A.
   b. Draw the effect of an increase in income, assuming the base value of the INCPAR parameter, on the demand curve. Label the new market equilibrium, B.

c. Draw the effect of an increase in income, assuming the new INCPAR parameter, on the demand curve. Label the new market equilibrium, C. How do the equilibrium quantities and price at C compare to those at equilibrium point B?
d. Are the industry output results, *qo*, and price results, *ps*, from your two CGE model scenarios consistent with your simple theoretical model?

5. Based on data from the SAMs for activity output in each country, how would you characterize the role of the tobacco sector in each economy? Based on these shares, how would you describe the likely size of economy-wide effects in each country of changes in tobacco preferences in ROW?
6. Write a short paragraph that describes your level of confidence in your model results for ROW's tobacco output, *qo*, and consumer demand for tobacco, *qp*. *Challenge:* present your results and your confidence interval in a graph, similar to that presented in Model Exercise 3.

Model Exercise 11: Deep Integration: Removing Tariffs and NTMs in the T-TIP

Concepts: Altertax, Non-Tariff Measures, Preferential Trade Agreements, Trade Creation, Trade Diversion

Background

In June 2013, the United States and the European Union launched negotiations on the Trans-Atlantic Trade and Investment Partnership (T-TIP). The agreement is intended to tackle some of the most complex issues that present barriers to their bilateral trade and investment. The T-TIP is expected to eliminate bilateral import tariffs and to achieve greater compatibility in trade and investment regulations while maintaining high levels of consumer health and safety and environmental protection (USTR, 2016). Successful harmonization of regulations, such as sanitary and phytosanitary requirements, will be an important achievement because these non-tariff measures (NTMs) are today substantially more restrictive of U.S.-EU trade and investment than tariffs (ECORYS, 2009).

An economic analysis of the potential economic impacts of the T-TIP is a challenging undertaking because it must describe the restrictive effects of both tariff and non-tariff measures on trade. The analysis of an import tariff in a CGE model is relatively straightforward. Import tariff rates are readily available to researchers because they are usually published by governments and other organizations. Their economic effect is to increase the domestic price of imports by the same proportion as the *ad valorem* tariff rates, which generally causes import quantities to fall and reduces economic efficiency and welfare. An analysis of the trade impacts of NTMs in a CGE model is more difficult because there is tremendous variation in types of NTMs, their objectives, and their method of implementation; they may have different effects on market behavior; and their restrictive effects on prices and trade volumes must be separately calculated or estimated by the researcher before they can be represented in a standard CGE model.

In an influential CGE-based study, Francois et al. (2013) modeled the protective effects of U.S. and EU NTMs in an analysis of the potential economic effects of a T-TIP. Their study built on research by ECORYS (2009) that quantified the *ad valorem* import tariff equivalents (AVEs) of NTMs that create barriers to U.S.-EU trade. ECORYS first conducted surveys of the business community to develop an index measure of the perceived restrictiveness of NTMs across a wide range of products. They utilized the index to represent an NTM variable in a gravity model, and then used the gravity model results to calculate the AVEs of import tariffs of NTMs. Based on a detailed review of the types of NTMs applied in each industry, Francois and his team allocated an average of 60% of the estimated AVEs to trade efficiency costs, and

Table ME 11.1. *Ad valorem equivalents of NTM trade barriers on U.S.-EU trade*

	EU-28 barriers on imports from U.S.				U.S. barriers on imports from EU-28			
	Total AVE	Trade efficiency cost (60%)	Exporter rent (13%)	Importer rent (27%)	Total AVE	Trade efficiency cost (60%)	Exporter rent (13%)	Importer rent (27%)
Average all goods	21.5	12.9	2.8	5.8	25.4	15.2	3.3	6.9
Food/ beverage	56.8	34.1	7.4	15.3	73.3	44.0	9.5	19.8
Services	8.5	5.1	1.1	2.3	8.9	5.3	1.2	2.4

Sources: ECORYS (2009) and Francois et al., 2013.

assumed that one-third of the remaining 40% were appropriately described as economic rents to exporters (modeled as export tax surcharges) and two-thirds as economic rents to importers (modeled as import tariff surcharges) (Table ME 11.1).

To analyze T-TIP, Francois and colleagues first created a "baseline" model experiment that imposed projected factor supply, population, and productivity growth in the global economy up to 2027. Next, they defined two T-TIP experiments that combined the growth projections of the baseline scenario with more and less ambitious scenarios of trade liberalization in a T-TIP. Their most ambitious scenario describes a complete elimination of bilateral import tariffs and a partial, 25% reduction in bilateral NTMs in goods and services. The assumed reduction in NTMs is less than complete because elimination of some measures is unrealistic, and others, such as quarantines for pests and disease, are mutually recognized as serving important public safety or technical functions and so are unlikely to be eliminated in trade negotiations. Their less ambitious scenario assumed a 98% reduction in bilateral tariffs and a 10% reduction in bilateral NTMs. The team also explored additional dimensions of trade liberalization, including third-country reductions of NTMs and reforms of government procurement regulations.

The research team found that the effects of the T-TIP on real GDP in the EU and United States are positive but likely to be quite modest. Results from the ambitious scenario, reported here, describe real GDP growth in both partners of less than 0.5% in 2027 relative to the baseline scenario without a T-TIP (Table ME 11.2). More of the real GDP growth results from the partial reduction in NTMs than from the full elimination of import tariffs.

The team found a substantial gain in the value of bilateral trade in 2027 in the ambitious scenario, which grows by $360 billion euros (in 2007 euros) relative to the baseline scenario. About 70% of the expansion in bilateral trade is due to the reduction of NTMs. Global trade increases by less than the

Table ME 11.2. *Changes in real GDP (in percent) due to an ambitious T-TIP compared to 2027 baseline without T-TIP*

Country	Real GDP 1/	Stemming from liberalization of		
		Tariffs	NTMs goods	NTM services
EU	0.40	0.11	0.26	0.03
United States	0.33	0.04	0.23	0.06

Source: Francois, et al., 2013, table 16.
1/The GDP effects exclude 3rd country and government procurement impacts.

increase in bilateral trade, indicating that some of the expansion in EU-U.S. trade is due to a diversion of their trade from the rest of the world.

Experiment Design

You will create a database named PTA3×3v8. The database has three regions (United States, EU-25, and Rest-of-world) and the same three sectors (AGR, MFG, and SER) and three factors (land, labor, and capital) as in the US3×3v8 database that you created in model exercise one.

The analysis has three steps. First, you will use GTAP's Altertax utility (Malcolm, 1998) to add surcharges to export taxes and import tariffs that represent the AVEs of bilateral NTMs in U.S.-EU trade, as estimated by ECORYS. After running the Altertax experiment, you will save the results as a new base model to be used with T-TIP experiments. Second, you will work with the updated tariff and subsidy data to calculate the changes in trade policies to be implemented in your T-TIP experiments. Third, you will run a set of three experiments that replicate the ambitious T-TIP scenario described by Francois and colleagues. The experiments will (1) eliminate all bilateral U.S.-EU import tariffs and export subsidies, while maintaining NTMs, (2) reduce NTMs by 25% while maintaining bilateral tariffs and export subsidies, and (3) combine an elimination of tariffs and subsidies with a 25% reduction in NTMs.

You will report three results for each experiment: (1) real GDP effects, (2) changes in bilateral trade quantities (trade creation and diversion), and (3) welfare impacts. A comparison of the results of experiments 1 and 2 allows you to compare the importance of tariffs/subsidies versus NTMs in the impacts of the trade agreement.

This modeling exercise offers a stylized replication of the Francois et al.'s analysis, and your results will differ from theirs for several reasons. Your analysis compares 2007 with and without a T-TIP, whereas Francois and colleagues created a baseline projection and compared 2027 with and without a T-TIP. Your analysis uses a standard, perfectly competitive CGE model that has only three sectors. The CGE model used by Francois and colleagues incorporates imperfect competition and has more detailed sectoral coverage and treatment of investment. Your model aggregation describes the 25-member European Union, prior to the entry of Bulgaria, Romania and Croatia, whereas Francois and colleagues describe a 28-member region. Your experiments are a subset of their ambitious T-TIP scenario, which also includes third-country reductions in NTMs and government procurement reforms, and to simplify your analysis, you also remove export taxes.

Instructions

1. Open the GTAP data aggregation program for version 8.1: GTAPAgg81y07

   You will create a three-country, three-sector, three-factor database.[4] The directions that follow are brief. If you are uncertain about any step, you can review its instructions in more detail in Model Exercise 1.
2. From the menu bar, select "View/Change Regional Aggregation"
   - In the column "New Region Code," change the names of the three default regions to "EU", "USA," and "ROW". The renaming of EU and ROW is an optional but convenient simplification of their names. Use the default definition of the **EU-25 region** in the aggregation software to represent the EU. Use of the default EU region definition simplifies this step in the model exercise.
   - In the mapping table, define USA to include only the United States. Place all other countries into the ROW region.
   - Click OK (this saves your regional aggregation).
3. Define the sectoral aggregation
   - From the menu bar, select "View/change sectoral aggregation"
   - The default aggregation defines 3 sectors: Agriculture, Manufacturing and Services. You will accept the default definition of these three sectors. (If the default definitions are not of these three sectors, then define AGR as sectors 1–14, MFG as sectors 15–42 and SER as sectors 43–57.).
   - Click OK (this saves your sectoral aggregation).
4. Define the factor aggregation.
   - From the menu bar, select "View/change factor aggregation"
   - In the table at the bottom of the page, right-click to remove all but three factor rows
   - In the left column, type "LAND," "LABOR," and "CAPITAL," putting one factor in each row
   - In the mapping table in the upper right quadrant, click on the center column, "New factor" and pull down the mapping menu, which should list "unmapped," "LAND," "LABOR," and "CAPITAL"

[4] As an alternative, you can download the same CGE model and database, called PTAToy, from the GTAP website at www.gtap.agecon.purdue.edu/access_staff/resources/res_display.asp?RecordID=4841.

- Map: land to LAND; skilled and unskilled labor to LABOR; and capital and natural resources to CAPITAL
- Define all factors as “mobile”
- Click on OK (this saves your factor definitions).

5. Save your data aggregation file
   - From the menu bar, select “Save aggregation scheme to file.” (GTAP provides a default name, “gtp3_3.agg,” which you can change to something descriptive, like “PTA3×3v8.agg”
   - Save this aggregation file in the folder that you created for your research project.
6. Create the aggregated database
   - From the menu bar, select “Create aggregated database.” This creates a zip file with the aggregated database. Give it the same name as your aggregation scheme (e.g., PTA3×3v8.zip), and save it in your project folder.
   - Close GTAPAgg81y07
   - Your database is now saved in zipped Header Array (HAR) files that are ready to use in your CGE model.
7. Create a version of the GTAP model with the PTA3×3v8 database

   Open the RunGTAP model by clicking on the Windows icon or opening it from your start menu. Create a new model version following the instructions in part D of Model Exercise 1. Give your model version a similar name as your aggregation scheme and database, (e.g., PTA3×3). The GTAP model will run a test simulation.
8. Change to the “condensed” GTAP model for the PTA3×3 model version

   The Altertax utility is compatible with the condensed version of the GTAP model. (Advanced modelers can adjust the Altertax parameter file and closures so that it also can be used with the uncondensed GTAP model.) Follow these steps to ensure that you are using the condensed GTAP model in the PTA3×3 model version:
   - Select “Version” from the menu bar
   - Select “Modules” from the drop-down menu
   - View the Main model row, and the Tab file column in the Version-Specific set of columns
   - If the cell contains “–” or GTAP, your model version is using the condensed GTAP model. Click OK to exit back to the RunGTAP model
   - If the cell contains “GTAPU,” then your model version is using the uncondensed model and you must change it to the condensed model
   - Click on the cell with GTAPU. This opens a menu.
   - Select the button for “NONE – use the global module in C:\RunGTAP5\GTAP*”
   - This step changes your model to the default, condensed model in your RunGTAP directory
   - Click on OK and OK to exit back to the RunGTAP model
   - Run a test simulation by selecting “Tools” from the menu bar, and selecting “Run Test Simulation” from the drop-down box.

9. Define the Altertax and T-TIP experiments

Before beginning your analysis, you must define the new import tariff and export subsidy rates to use in the Altertax update and for the three T-TIP experiments.

a. View the original bilateral tariffs in your model and report them in column A of Table ME 11.3
   - Select "View" from the menu bar at the top of the page
   - Select "Base Data" from the drop-down menu
   - Select "Tax Rates" from the drop-down menu
   - Select "RTMS – % ad valorem rate, import taxes by source"
   - View and report the EU import tariffs on the United States by setting toggles to

   All TRAD_COMM/USA/EU
   - View the U.S. import tariffs on the EU by setting the toggles to
   - All TRAD_COMM/EU/USA
   - Report U.S. tariffs in table ME 11.3
   - Double-click on any number to return to the list of tax rates
   - Select "RTXS – % ad valorem export subsidy rate, by destination"
   - View and report the EU export subsidies on exports to the United States by setting the toggles to
     All TRAD_COMM/EU/USA
   - View and report the U.S. export subsidy (note, it is a tax) on exports to the EU by setting toggles to:
     All TRAD_COMM/USA/EU
   - Click on the red X in the upper right corner to close ViewHAR.

b. Report the Francois et al.'s AVE's of import tariffs and export taxes for each sector, from Table ME 11.1, into column B of Table ME 11.3. Assume that the NTM for the "Food and beverage" sector describes bilateral trade barriers in AGR in the PTA3×3v8 model, and that the NTM for "All goods" describes trade barriers in MFG. Note that the GTAP model describes export policies as subsidies, so an export tax is expressed in the database as a negative number.

c. Follow the instructions in the formula row of Table ME 11.3 to calculate data for the other columns of the table. These rates will be used in your model experiments. For experiment 1 – T-TIP tariff removal only, the original import tariff and export subsidy or tax rates are removed and only the AVE of NTMs remains in place. For experiment 2 – TTIP NTM removal only, the new tariff and subsidy rates are the sum of the original rates plus 75% of the AVE (assuming 25% of the AVE of NTM is reduced in an ambitious scenario). In experiment 3, T-TIP eliminates tariffs and subsidies and 25% of the AVE of NTMs, leaving 75% of the AVE of NTMs.

d. Calculate changes in trade costs for your experiments in Table ME 11.4. First, report the AVE of NTM's trade efficiency costs estimated by ECORYS from Table ME 11.1. In this experiment, the trade

Table ME 11.3. *Define import tariff and export subsidy rates for the Altertax and T-TIP experiments*

	EU bilateral trade policies					U.S. bilateral trade policies				
Formula	A	B	A + B	A + .75 ∗ B	.75 ∗ B	A	B	A + B	A + .75 ∗ B	.75 ∗ B
Model experiment	Base tariff and subsidy rates	EXP. 1:T-TIP with tariff/ subsidy removal only	Altertax update	EXP. 2: T-TIP with NTM reduction only	EXP. 3: "Ambitious" T-TIP scenario	Base tariff and subsidy rates	EXP. 1:T-TIP with tariff/ subsidy removal only	Altertax update	EXP. 2: T-TIP with NTM reduction only	EXP. 3: "Ambitious" T-TIP scenario
Import tariff	2007 rate	AVE of NTM (importer rent)	Import barriers including AVE of NTM	Import barriers after reducing NTMs only in T-TIP	Import barriers after eliminating tariffs and subsidies and reducing NTMs 25%	Base rate	AVE of NTM (importer rent)	Tax rate including AVE of NTM	Import barriers after removing NTMs only in T-TIP	Import barriers after eliminating tariffs and subsidies and reducing NTMs 25%
AGR										
MFG										
SER										
Export subsidy	2007 rate	AVE of NTM (exporter rent)	Subsidy rate including AVE of NTM	Export barriers after reducing NTMs only in T-TIP	Export barriers after eliminating tariffs and subsidies and reducing NTMs 25%	Base rate	AVE of NTM (exporter rent)	Subsidy rate including AVE of NTM	Export barriers after removing NTMs only in T-TIP	Export barriers after eliminating tariffs and subsidies and reducing NTMs 25%
AGR										
MFG										
SER										

Notes: Base import tariff and export subsidy rates are from GTAP v8.1. We use ECORYS' food and beverage AVE for AGR and their AVE for all goods for the MFG sector. The 25% reduction in the AVE of NTMs is based on the ambitious T-TIP scenario defined in Francois et al. (2013).
Sources: Author calculations based on GTAP v8.1 PTA3×3 database and ECORYS (2009).

Table ME 11.4. *Define the changes in trade efficiency for TTIP experiments*

	EU import barriers – trade efficiency of imports to the EU		U.S. import barriers – trade efficiency of imports to the United States	
Formula	A	B = .25 ∗ A	A	B = .25 ∗ A
Model experiment	AVE of NTM	EXP 2 and 3: TTIP with NTM reduction	AVE of NTM	EXP 2 and 3: TTIP with NTM reduction
	AVE of trade efficiency cost of NTMs	25% increase in trade efficiency due to T-TIP	AVE of trade efficiency cost of NTMs	25% increase in trade efficiency due to T-TIP
AGR				
MFG				
SER				

Notes: Base value of trade productivity is implicitly equal to one. We use ECORYS' food and beverage AVE of NTM for the AGR sector, and their AVE for all goods for the MFG sector. The increase in trade efficiency is calculated as a gain equal to 25% of the trade efficiency cost of the NTM in the ambitious T-TIP scenario defined in Francois et al. (2013).
Sources: Author calculations based on data in Francois et al. (2013).

agreement increases trade efficiency by 25% of the estimated AVE of the import barriers. For example, if the estimated AVE of the barrier's trade efficiency cost is 44%, then a 25% reduction in its trade cost is modeled as an 11% increase in trade productivity. Report your calculations to two decimal places. In the GTAP model, the trade efficiency parameter is variable $ams_{i,r,s}$. Because the base value for the this parameter is implicitly 1, it is not reported in the table.

10. Use Altertax to update import tariffs and export taxes to add AVEs of NTMs
    - Open the ALTERTAX utility:
      - Select "Tools" from the upper menu bar
      - Select "Altertax" from the drop-down menu
      - You may choose to press "Help" to learn more about this utility.
      - OK
      - OK (this loads the Altertax closure and parameter files)
      - OK (this will open up the closure page with new Altertax closures)
11. Explore the AlterTax closure and parameters:
    a. View the closure statement (This page should automatically open when you open the Altertax utility. If not, select Closure from the page tabs.)

    Notice the additional closure statements that fix the U.S. and EU trade balances at their base levels. This minimizes changes in trade flows due to newly adjusted tax rates.

b. View the new elasticity parameters.
   - Select "View" from the upper menu bar
   - Select "Parameters" from the drop-down box
   - Select INCPAR. Notice that all income elasticity parameters have been set to 1. A unitary income elasticity minimizes changes in the shares of goods in the consumer basket due to changes in income that result from newly adjusted taxes. You may wish to explore other elasticity parameters and think about how their Altertax values work to preserve the original structure, or shares, in an economy.
   - Click on the red X in the upper right corner to close ViewHAR.

12. Set up the Altertax experiment to add AVEs of NTMs as surcharges to original import tariffs and export subsidies
   a. Redefine EU tariffs on imports from the United States
      - Select the "Shocks" page tab
      - Select from the "Variable to Shock" drop-down menu: *tms*
      - Select from the "Elements to Shock" drop-down menu: AGR, USA, EU
      - In "Shock Value" box, enter: 18.82 (import tariff rate including AVE of NTM from the Altertax column in Table ME 11.3.)
      - In "Type of Shock," enter: % target rate
      - Click on "Add to Shock list"
      - Repeat this update for all MFG and SER imports by the EU from the U.S.
   b. Redefine EU export subsidies on exports to the United States
      - Select the "Shocks" page tab
      - Select from the "Variable to Shock" drop-down menu: *txs*
      - Select from the "Elements to Shock" drop-down menu: AGR, EU, USA
      - In "Shock Value" box, enter: -7.28 (export subsidy rate including AVE of NTM from the Altertax column of Table ME 11.3)
      - In "Type of Shock," enter: % target rate
      - Click on "Add to Shock list"
         - Repeat this update for all MFG and SER exports from the EU to the U.S.
   c. Repeat these steps to redefine U.S. import tariff and export subsidy rates using your calculations in Table ME 11.3.

13. Solve the model
   - Select the "Solve" page tab
     Notice that the AlterTax utility automatically defines the solution method as Gragg: 2-4-6 and defines the parameter file to be altertax.
   - Click on "Save experiment," name the shock TTIPAlt. Use its default description of "Altertax."
   - OK
   - Click on "Solve"
   - OK
   - OK.

14. Verify your shock by reviewing updated tax and subsidy rates. (These rates should all be approximately equal to your calculated rates in Table ME 11.3.)

15. Save the results of the Altertax update as your new base model
    - Select "Version" from the menu bar at the top of the page
    - Select "New"
    - Next (this opens options to define the new version)
    - Select these options to define your new version:
    - Based on: "Same aggregation as the current version"
    - Adapt current version by "Using the updated database"
    - Name the updated model "PTA3×3v2"
    - Next
    - Next
    - Finished
    - OK (The GTAP software will create your model and run a numeraire experiment as a consistency check. When this step is complete, your new model with updated tax and subsidy rates is ready to use for trade liberalization experiments.)
    - Optional – Provide a description of your updated model on the "Version" page tab. Follow instructions in Part D of Model Exercise 1.
16. Set up Experiment TTIP1 – elimination of import tariffs and export subsidies
    a. Select the Shocks page tab
    b. Eliminate EU import tariffs on AGR imports from the United States
       - Select from the "Variable to Shock" drop-down menu: *tms*
       - Select from the "Elements to Shock" drop-down menu:

         AGR, USA, EU

       - In "Shock Value" box, enter: 15.30 (from the Experiment 1 column in Table ME 11.3)
       - In "Type of Shock," enter: % target rate
       - Click on "Add to Shock List"
    c. Repeat this for all U.S. and EU bilateral import barriers
    d. Eliminate EU subsidies on exports to the United States
       - Select from the "Variable to Shock" drop-down menu: *txs*
       - Select from the "Elements to Shock" drop-down menu:

         AGR, EU, USA

       - In "Shock Value" box, enter: -7.40 (from table ME 11.3)
       - In "Type of Shock," enter: % target rate
       - Click on "Add to Shock List"
       - Repeat this for all EU and U.S. bilateral export subsidies
    e. Save the experiment
       - Select the "Solve" page tab
       - Check that the solution method is: Gragg (accepting the default number of 3 solutions and 2-4-6 steps per solution)
       - Check that the parameter file is the Default parameter file
       - Click on "Save" and name the experiment "TTIP1," describing it as "Eliminate tariffs and subsidies in TTIP"

Table ME 11.5. *Changes in Real GDP (in percent) due to TTIP*

Country	Total – ambitious scenario (T-TIP3)	Stemming from: Tariff/subsidy elimination only (T-TIP1)	Stemming from: NTM reduction only (T-TIP2)
EU			
United States			

Note: Results for GTAP variable *qgdp*.
Source: GTAP model, GTAP v8.1 PTA3×3v2 database.

17. Solve the model
    - Check that the solution method is Gragg 2-4-6 steps extrapoliation
    - Check that the parameter file is "Default"
    - Click on "Solve"the "Solve" page tab
18. Review updated tax and subsidy rates (these rates should all be approximately equal to your calculated rates in table ME 11.3)
19. Report results of Experiment TTIP1
    a. Report change in real GDP in Table ME 11.5
       - Click on the "Results" page tab
       - From the alphabetical list of variables, click on "*qgdp* – GDP quantity index"
       - Report *qgdp* results from the sim column. This column displays the percentage change in the variable due to the experiment.
       - Double-click anywhere in table to return to list of variables.

    b. Report the percentage changes in import quantities in Table ME 11.6
       - From the alphabetical list of variables, click on "*qxs* – export sales of commodity i from r to region s"

Table ME 11.6. *Percent Changes in Quantity of Bilateral Imports due to TTIP*

Country	Total – ambitious scenario (T-TIP3)	Stemming from: Tariff/subsidy elimination only (T-TIP1)	Stemming from: NTM reduction only (T-TIP2)
EU to United States			
Agriculture			
Manufacturing.			
Services			
United States to EU			
Agriculture			
Manufacturing			
Services			

Note: Results report GTAP variable $qxs_{i,r,s}$
Source: GTAP model, GTAP v8.1 PTA3×3v2 database.

This will open an error box, “Sorry, you cannot view a 3-D matrix unless filtering on an element name.” Click on OK to close the message.

- Filter the results by selecting the drop-down box on the upper left hand side, labeled “Everything.” Select EU from the list.
- Select *qxs*(*,EU,*) from the list. This variable reports the percentage change in quantity of EU exports of commodity *i* to region *s*.
- Report the percentage change in EU exports quantities to the USA.
- Change the filter from EU to USA.
- Report the percentage change in U.S. export quantities to the EU.
- Close the file by clicking on the red X in the upper right corner.

20. Set up Experiment TTIP2: Reduce NTMs 25% but retain import tariffs and export subsidies
    a. Reduce NTMs modeled as import tariffs and export subsidies by 25%. Follow the same steps as in experiment one, except that you will change bilateral import tariffs and export subsidies to the levels described as Experiment 2 in Table ME 11.3.
    b. Increase bilateral trade efficiency by 25%
       - Select from the “Variable to Shock” drop-down menu: *ams*
       - Select from the “Elements to Shock” drop-down menu:

         AGR, USA, EU
       - In “Shock Value” box, enter: 8.53 from the “Experiment 2 and 3” column in Table ME 11.4
       - Click on “Add to Shock List”
    c. Repeat this for all EU and U.S. bilateral trade costs due to NTMs
    d. Save the experiment
       - Select the “Solve” page tab
       - Check that the solution method is: Gragg (accepting the default number of 3 solutions and 2-4-6 steps per solution)
       - Check that the parameter file is the Default parameter file
       - Click on “Save” and name the experiment “TTIP2,” describing it as “Reduce NTMs only”
    e. Solve the model
       - Click on “Solve”
       - OK
       - OK
    f. Verify your shock by reviewing the updated tax and subsidy rates.
21. Report results of TTIP experiment 2 in in Tables ME 11.5–11.6.
22. Set up T-TIP experiment 3: Ambitious T-TIP scenario (eliminates import tariffs and export subsidies, and reduces NTMs by 25%)
    a. Follow the aforementioned directions to reduce the (NTM inclusive) EU and U.S. import tariffs and export subsidies to the levels that you calculated in the Experiment 3 column of Table ME 11.3.
    b. Follow the directions in step 20 to increase trade productivity on EU-U.S. bilateral trade by 25%, as calculated in Table ME 11.4.

Table ME 11.7. *Welfare Impacts of a T-TIP ($US millions)*

	Allocative efficiency	Technical efficiency	Terms of trade (goods)	Terms of trade (savings-investment)	Total
United States					
EU					

Source: GTAP model, GTAP v8.1 PTA3×3v2 database.

c. Follow the directions above to save your experiment and solve the model.
d. Verify your shock by reviewing the updated tariff and subsidy rates, and productivity gains.
e. Report your results in Tables ME 11.5 and 11.6.

23. Report the welfare effects of TTIP Experiment 3 in Table ME 11.7
    - Select "View" from the menu bar at the top of the page
    - Select "Updated Data" from the drop-down menu
    - Select "Welfare decomposition"
      This will open the overview page of the welfare utility.
    - From the list of welfare components, double-click on "EV Decomposition: Summary," in the first row of the list.
    - Report welfare results for the United States and EU in the table.
    - Close the file by clicking on the red X in the upper right corner.
24. Report the trade creation and diversion effects of TTIP Experiment 3 in Table ME 11.8

Table ME 11.8. *Trade Creation and Trade Diversion due to TTIP ($US millions)*

	Change in real EU imports from U.S.	Change in real EU imports from ROW
Agriculture		
Manufacturing.		
Services		
	Change in real U.S. imports from EU.	Change in real U.S. imports from ROW
Agriculture		
Manufacturing		
Services		

Note: Units are real values in 2007 dollars.
Source: GTAP model, GTAP v8.1 PTA3×3v2 database.

a. Report changes in real quantities of EU imports
   - Click on the Results page tab
   - From the drop-down menu on the upper left side, which says "Everything," filter the results by choosing EU.

- Select variable "qxs(*,*,EU)
- From the drop-down box which says "1-Sim"choose "4 Ch/%Ch". (This reports the change in the level of real (quantity) EU imports valued in $US 2007 dollars, weighted by initial exporter producer prices.)
- View and report in Table ME 11.8 the changes in quantities imported by the EU from the United States and the rest of the world

b. Report changes in quantities of U.S. imports

Change the filter toggle from EU to the US. View and report in Table ME 11.8the changes in real imports by the U.S. from the EU and the rest of the world.

Interpret Model Results

1. Define "NTM." Explain the three ways that an ad valorem equivalent of an NTM can be represented in standard CGE models. What are some limitations of these approaches?
2. What is meant by trade inefficiency? How does an "iceberg" trade cost describe trade inefficiency? Provide a real-world example of how an NTM can reduce trade efficiency.
3. What are your sources of data for the AVEs of NTMs in this experiment? How were they allocated across tariffs, export subsidies and trade costs? How important is this allocation, and what factors do you think might be important to consider in making this decision?
4. Compare the empirical importance of the liberalization of NTMs versus removal of import tariffs/export subsidies and taxes in U.S.-EU trade on the impacts of the T-TIP in your study's results. How do your results compare with the conclusions of Francois, et al.? What are some reasons for why they might differ?
5. Is the TTIP welfare-improving for the EU, the United States and the world? Explain the most important drivers of these welfare gains and losses.
6. Define the concepts of trade creation and trade diversion. Is the ambitious T-TIP agreement net trade creating or trade diverting for the EU and the United States? What variable(s) in your model describe trade creation and diversion effects?

Appendix A

Social Accounting Matrix for the United States, 2007 $U.S. Billions

	Commodities												Indirect Taxes				
	Imported Variety			Domestic Variety			Production Activity			Factors of Production			Trade Taxes		Sales Tax on Imported Variety		
	AGR	MFG	SER	AGR	MFG	SER	AGR	MFG	SER	Land	Labor	Capital	Import Tariff	Export Tax	AGR	MFG	SER
Import–AGR	0	0	0	0	0	0	1	15	5	0	0	0	0	0	0	0	0
Import–MFG	0	0	0	0	0	0	9	797	300	0	0	0	0	0	0	0	0
Import–SER	0	0	0	0	0	0	1	22	236	0	0	0	0	0	0	0	0
Domestic–AGR	0	0	0	0	0	0	35	165	21	0	0	0	0	0	0	0	0
Domestic–MFG	0	0	0	0	0	0	62	2,007	1,502	0	0	0	0	0	0	0	0
Domestic–SER	0	0	0	0	0	0	86	1,329	4,821	0	0	0	0	0	0	0	0
Activity–AGR	0	0	0	326	0	0	0	0	0	0	0	0	0	0	0	0	0
Activity–MFG	0	0	0	0	6,657	0	0	0	0	0	0	0	0	0	0	0	0
Activity–SER	0	0	0	0	0	18,212	0	0	0	0	0	0	0	0	0	0	0
Land	0	0	0	0	0	0	36	0	0	0	0	0	0	0	0	0	0
Labor	0	0	0	0	0	0	47	1,361	6,797	0	0	0	0	0	0	0	0
Capital	0	0	0	0	0	0	53	649	2,846	0	0	0	0	0	0	0	0
Import tariff	1	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Export tax	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0
Sales tax–AGR import	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sales tax–MFG import	0	0	0	0	0	0	0	4	7	0	0	0	0	0	0	0	0
Sales tax–SER import	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sales tax–AGR dom.	0	0	0	0	0	0	–1	0	0	0	0	0	0	0	0	0	0
Sales tax–MFG dom.	0	0	0	0	0	0	0	11	45	0	0	0	0	0	0	0	0
Sales tax–SER dom.	0	0	0	0	0	0	–4	4	6	0	0	0	0	0	0	0	0
Factor use tax–land	0	0	0	0	0	0	–1	0	0	0	0	0	0	0	0	0	0
Factor use tax–labor	0	0	0	0	0	0	4	205	1,023	0	0	0	0	0	0	0	0
Factor use tax–capital	0	0	0	0	0	0	–2	21	93	0	0	0	0	0	0	0	0
Production tax	0	0	0	0	0	0	1	70	511	0	0	0	0	0	0	0	0
Income tax	0	0	0	0	0	0	0	0	0	3	1,742	294	0	0	0	0	0
Regional household	0	0	0	0	0	0	0	0	0	33	6,463	1,994	24	3	1	59	0
Household	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Government	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Savings–investment	0	0	0	0	0	0	0	0	0	0	0	1,260	0	0	0	0	0
Trade margin–import	5	81	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trade margin–export	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rest-of-world	28	1,797	315	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	34	1,901	315	326	6,660	18,212	326	6,657	18,212	36	8,205	3,548	24	3	1	59	0

Appendix A (*continued*)

	Indirect Taxes									Final Demand						
	Sales Tax on Domestic Variety			Factor Use Taxes				Direct Tax					Trade/Transport Margins			
	AGR	MFG	SER	Land	Labor	Capital	Production Tax	Income Tax	Regional House-Hold	Private House-Hold	Gov't.	Saving/ Investment	Import Margin	Export Margin	Rest-of-World	Total
Import–AGR	0	0	0	0	0	0	0	0	0	13	0	0	0	0	0	34
Import–MFG	0	0	0	0	0	0	0	0	0	501	0	294	0	0	0	1,901
Import–SER	0	0	0	0	0	0	0	0	0	51	0	4	0	0	0	315
Domestic–AGR	0	0	0	0	0	0	0	0	0	53	0	0	0	0	52	326
Domestic–MFG	0	0	0	0	0	0	0	0	0	1,355	0	764	0	0	970	6,660
Domestic–SER	0	0	0	0	0	0	0	0	0	7,742	2,258	1,604	0	28	345	18,212
Activity–AGR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	326
Activity–MFG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6,657
Activity–SER	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18,212
Land	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	36
Labor	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8,205
Capital	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3,548
Import tariff	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24
Export tax	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
Sales tax–AGR import	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
Sales tax–MFG import	0	0	0	0	0	0	0	0	0	43	0	5	0	0	0	59
Sales tax–SER import	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sales tax–AGR dom.	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1
Sales tax–MFG dom.	0	0	0	0	0	0	0	0	0	137	0	12	0	0	0	204
Sales tax–SER dom.	0	0	0	0	0	0	0	0	0	51	0	1	0	0	0	58
Factor use tax–land	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	– 1
Factor use tax–labor	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,232
Factor use tax–capital	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	112
Production tax	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	581
Income tax	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2,039
Regional household	1	204	58	– 1	1,232	112	581	2,039	0	0	0	0	0	0	0	12,802
Household	0	0	0	0	0	0	0	0	9,949	0	0	0	0	0	0	9,949
Government	0	0	0	0	0	0	0	0	2,258	0	0	0	0	0	0	2,258
Savings–Investment	0	0	0	0	0	0	0	0	594	0	0	0	0	58	773	2,686
Trade margin–import	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	86
Trade margin–export	0	0	0	0	0	0	0	0	0	0	0	0	86	0	0	86
Rest-of-world	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2,139
Total	1	204	58	– 1	1,232	112	581	2,039	12,802	9,949	2,258	2,686	86	86	2,139	

Source: GTAP version 8.1 (2013).

Appendix B
Price and Quantity Variables and Definitions in a Standard CGE Model

Price variable	Quantity variable	Set domain	Price definition
			Non-composite prices
PCIF	QMS	i,r,s	***Bilateral cif import price*** is the exporting country *r*'s *fob* price for quantity of bilateral imports (QMS) of good *i* plus bilateral insurance and freight charges on its shipment to country *s.*
PD	QD	i,r	***Consumer domestic price*** of the quantity of the domestically-produced variety (QD) of good *i* is the sum of its producer sales price plus the retail sales tax.
PDS	QD	i,r	***Producer domestic price*** is the sales price received by producers in country *r* for the quantity of the domestically-produced variety (QD) of good *i* sold in the domestic market.
PFOB	QXS	i,r,s	***Bilateral fob export price*** for quantity of bilateral exports (QXS) of good *i* from country *r* to country *s* is the producer sales price plus r's bilateral export tax on sales from *r* to *s.*
PM	QM	i,r	***Consumer import price*** is the domestic consumer price of the quantity of the composite import (QM) of *i* by country *r* plus the retail sales tax.
PMS	QMS	i,r,s	***Bilateral domestic price of an import*** is the bilateral *cif* import price of the quantity of bilateral imports (QMS) of good *i* imported from country *r* by country *s*,plus the bilateral tariff in country *s* on good *i.*
PS	QO	i,r	***Producer supply price*** equals the cost of production plus production taxes, for quantity of domestic production (QO) good *i* in country *r.*

(*continued*)

Appendix B (*continued*)

Price variable	Quantity variable	Set domain	Price definition
			Non-composite prices
W_i, R_i	QFE	f,i,r	***Wage or rent*** for quantity (QFE) of factor *f* employed in industry *i* in country *r*
			Composite prices
P	Q	i,r	***Consumer market price*** of consumption quantity (Q) of composite commodity *i* in country *r* is the weighted sum of the consumer import price and the consumer domestic price. Weights are the quantity shares of the imported and the domestic varieties in the consumer basket.
PIM	QM	i,r	***Domestic consumer price of imports*** the import-share weighted sum of the bilateral domestic prices of the composite (aggregate) quantity (QM) of imports of good *i* by country *r* (includes tariffs).
PINT	QINT	i,r	***Composite input price*** for quantity bundle (QINT) is the share-weighted price of intermediate inputs in industry *i* in country *r* where weights are input shares in QINT.
PVA	QVA	i,r	***Composite value added price*** for quantity bundle (QVA) of factor inputs in industry *i* in country *r* is the share-weighted price of factor inputs where weights are shares of each factor in QVA.
PWE	QE	i,r	***World export price*** for composite (aggregate) exports (QE) of good *i* from country r is the export-share weighted sum of its bilateral *fob* export prices.
PWM	QM	i,r	***World import price*** for composite (aggregate) imports (QM) of good *i* by country *r* is the import-share weighted sum of its bilateral *cif* import prices (excludes tariffs).
PXW	QW	i	***World price*** of the total quantity of world trade (QW) in good *i* is the sum of all of the bilateral, *fob* export prices of *i* in all countries in the world, weighted by their export shares in the total quantity of global trade.
W, R	QF	f,r	***Economy-wide wage or rent*** for aggregate supply (QF) of factor *f* in country *r* is the industry-weighted sum of industry wages and rents.

Glossary

Activity is the domestic production of a good or service.

Ad valorem equivalent (AVE) is a tax that has the equivalent effects on market prices and quantities as a regulation.

Ad valorem tax is a tax levied as a percentage of value.

Agents include industries, factors of production (e.g., labor and capital), household consumers, the government, investors, and the rest-of-world region, which supplies imports and demands exports.

Baseline scenario introduces projected growth in population, factor supplies, productivity, and policies as a model experiment.

Behavioral equation: *see* equation, behavioral.

Budget constraint is the amount of income received by a consumer that is then allocated to consumption, savings, and taxes.

Budget share is the value share of each good or service in total expenditure.

Calibration is a procedure that calculates quantities and normalized prices, and the shift and share parameters used in the production and utility functions in the CGE model so that the solution to model equations replicates the initial equilibrium as reported in the base data.

cif: *see* cost, insurance, freight.

Circular flow of income and spending describes transactions in an economy: Firms buy inputs and pay wages and capital rents to factors used in the production of goods and services. Firm payments to factors are the income earned by households and spent on goods and services, government taxes, and savings. Taxes and savings lead to government and investment demand. Firms respond to demand by buying inputs and hiring labor and capital.

Closure defines whether a variable is endogenous or exogenous.

Commodity is a composite intermediate input or consumption good, composed of domestically produced and imported varieties; in some CGE models, it is a composite production good, composed of varieties produced for domestic and export sales.

Compensated demand curve implies that the government compensates consumers dollar for dollar for their tariff expenditure. This compensation assumption allows all quantity changes due to a tax to be attributed to the substitution effect (which is the excess burden) because the compensation cancels any income effects of the tax.

Complements are inputs or consumption goods that are used together, so that a rise in the price of one input or good causes demand for the other to fall.

Composite commodity: *see* commodity

Composite price is a weighted sum of prices.

Computable general equilibrium (CGE) model describes an economy as a whole and the interactions among its parts. It is solved to find the set of prices at which quantities of supply and demand are in equilibrium in all markets.

Consumer price is the price paid by consumers. It is the domestic producer price plus sales tax, or bilateral *cif* import price plus import tariff and sales tax.

Consumer price of imports is the *cif* import price plus import tariffs.

Cost-insurance-freight (*cif*) is the value of an import, including the cost of insurance and freight service used in its international transport.

Deadweight loss is the loss in producer and consumer surplus that is not recouped elsewhere in the economy.

Depreciation is that portion of investment spending that replaces worn-out capital stock.

Deterministic CGE model provides unique solution values for each variable, given model equations, parameters, and base data.

Direct burden is the amount of tax paid to the government.

Direct cost of a regulation is the deadweight efficiency loss in a market due to its regulation.

Direct tax is a tax that is levied on factors or individuals and whose burden cannot be passed on to other agents.

Downstream industries are the production activities that use the output of other, "upstream" industries as intermediate inputs into their production process.

Dutch Disease describes the deindustrialization of an economy when an increase in the world price of a natural resource export price leads to an expansion of the booming resource sector, higher incomes and spending, and real exchange rate appreciation.

Dynamic CGE model describes a country's long-run growth path, with capital accumulation and productivity growth.

Effective factor price is the wage or rental paid per unit of effective labor or capital.

Effective import price is the price paid per unit of effective import quantity.

Effective import quantity is the export quantity shipped by the exporter minus its iceberg trade costs (the quantity of itself used up in its transport).

Elasticity is an exogenous parameter in a CGE model that describes the responsiveness of supply or demand to a change in prices or income.

Elasticity, aggregate input substitution in the production of good *i* describes the percent change in the ratio of the value-added bundle to the intermediate input bundle in the final product, given a percent change in their inverse price ratio, holding final output constant.

Elasticity, export demand for commodity *i* describes the percent change in a country's world market share given a percent change in the ratio of the average global price to its *fob* export price.

Elasticity, export transformation in production of good *i* describes the percent change in the quantity ratio of exports to domestic sales given a percent change in the ratio of the domestic sales price to the *fob* world export price, holding output of *i* constant.

Elasticity, factor mobility for factor *f* describes the percent change in an industry's quantity share in total employment of a factor given a percent change in the ratio of the economy-wide average factor price to the industry's wage or rent, holding national supply of the factor constant.

Elasticity, factor substitution for industry *i* describes the percent change in the quantity ratio of a factor to total factor inputs given a percent change in the inverse ratio of the factor's price relative to the prices of other factors, holding the value-added bundle constant.

Elasticity, import substitution between domestic and import (Armington) for commodity *i* describes the percent change in the quantity ratio of imported to domestic varieties given a percent change in their inverse price ratio, holding consumption of *i* constant.

Elasticity, import substitution among foreign sources of import (Armington) for commodity *i* describes the percent change in the quantity ratio of imports from partner *j* and partner *k* given a percent change in their inverse price ratio, holding imports of *i* constant.

Elasticity, income for commodity *i* describes the percent change in quantity demanded given a percent change in income.

Elasticity, intermediate input substitution for industry *i* describes the percent change in the quantity ratios of intermediate inputs given a percentage change in the inverse ratio of input prices, holding the quantity of composite inputs constant.

Elasticity, own price for commodity *i* describes the percent change in quantity demanded given a percent change in its price.

Elasticity, price transmission measures the percent change in one price given a percent change in another price.

Elasticity, substitution in consumption between commodities *i* and *j* describes the percent change in the quantity ratios in a given consumer basket, relative to a percent change in their inverse price ratio, for a given level of utility.

Endogenous variable has a value that is determined as the solution of a model equation.

Equation, behavioral describes the economic behavior of producers or consumers based on microeconomic theory.

Equation, identity defines a variable as a mathematical function (sum, product, etc.) of other variables. It describes an accounting relationship or imposes a market clearing constraint. Closure rules specify which variable adjusts to maintain the constraint.

Equilibrium occurs when the quantities of supply and demand are in balance at some set of prices.

Equivalent variation: *see* welfare, equivalent variation.

Excess burden is the loss in economic efficiency when producers and consumers change the quantities that they produce or consume to avoid a tax.

Exchange rate, nominal measures the rate at which currencies are exchanged for one another.

Exchange rate, real measures the relative prices of traded to non-traded goods.

Exogenous parameters in a CGE model are tax and tariff rates, elasticities of supply and demand, and the calibrated shift and share coefficients used in supply-and-demand equations.

Exogenous variable is a variable whose value is taken as given and does not change when model equations are solved.

Externality is the negative or positive spillover effect of an economic transaction between two partiers, which is not reflected in market prices.

Factor is a primary productive resource, such as land, labor, or capital, that is combined with intermediate inputs to produce goods and services.

Factor endowments are the stocks of labor, capital, and other primary factors that constitute the productive resource base of an economy.

Factor endowment, effective is the stock of a factor that takes into account both the quantity and the efficiency of a factor.

Factor, fully mobile moves across production activities within a country in response to changes in relative wages and rents, until wages and rents are equalized.

Factor intensity is measured by the relative size of factors' input-output coefficients. The comparison of coefficients can be made across factors within a production activity, or by comparing a factor's coefficient across industries or countries. An activity is intensive in a factor if the coefficient for that factor is higher than for other factors, higher for that factor compared to other activities, or higher for that factor compared to the same activity in other countries.

Factor mobility describes the ease with which labor, capital, and other factors can move to new employment within a country when wages and rents differ across production activities.

Factor, partially mobile is a factor for which transition costs are important enough to discourage it from changing its employment unless pay differences across industries are sufficient.

Factor price is the wage or rent paid to a factor by the production activity that employs it.

Factor price, effective is the wage or rent paid per unit of effective factor quantity.

Factor productivity describes the level of output per unit of factor input.

Factor, sector-specific (immobile) does not move from the production activity in which it is originally employed, regardless of differences in relative wages or rents across production activities.

Factor unemployment describes factors that are not employed by any production activity and are not counted as part of the productive capacity of an economy.

Factors, complementary describe factors for which an increase (decrease) in the use of one factor in the production process requires an increase (decrease) in use of the other.

Factors, substitute describe factors that can replace one another in the production of a good or service.

Final demand is the demand for goods and services in their end-use; they are not further combined or processed into other goods and services.

fob: *see* free on board.

Free-on-board (fob) is the value of the export good, including export taxes but excluding the *cif* costs paid by the importer.

Gross complement: Two goods are gross complements if a decline in the price of one good causes the quantity demanded of the second good to rise.

Gross Domestic Product (GDP) from the expenditure side reports the allocation of national income across four categories of spending: private consumption (C), investment demand (I), government demand (G), and net exports (E-M).

Gross Domestic Product (GDP) from the income side reports the sources of total national income from the wages and rents earned by factors of production, taxes on economic activity, and depreciation.

Gross substitute Two goods are gross substitutes if a decline in the price of one good causes the quantity demanded of the second good to fall.

Gross value of output of a production activity is the sum of value-added plus the cost of intermediate inputs. It is the market value of industry output and reported as the sum total of the activity column in the SAM.

Hecksher-Ohlin theorem posits that countries will export goods that are intensive in the factors of production that are in relatively abundant supply, and import goods that are intensive in the factors of production that are in relatively scarce supply.

Homothetic utility function assumes an income elasticity of demand of one so that the percentage change in quantity demanded is the same as the percentage change in income.

Iceberg trade cost is the portion of the traded good that is used up, or "melted away," in its transport from the exporter to the importer.

Identity equation: *see* equation, identity.

Immobile factor (sector-specific) is a factor that remains fixed in its original sector of employment.

Import (Armington) aggregation function describes how imported and domestic varieties are combined to produce a commodity.

Independent goods or factors are items for which demand does not change when the prices of other goods or factors change.

Indifference curve describes all possible combinations of commodities that yield the same level of utility or satisfaction to the consumer.

Indirect costs of a regulation are (1) changes in total production of externalities that result from changes in industry size and composition, (2) second-best efficiency effects and (3) terms of trade.

Inferior good is a good for which demand declines as income grows.

Input-output coefficient describes the ratio of an intermediate or factor input per unit of output.

Input-output coefficient matrix displays the input-output coefficients of all inputs in every production activity. The matrix shows how industries are linked through their demand for intermediate inputs.

Intermediate input is a good that is combined with other inputs and factors to produce a final product.

Intermediate input intensity is measured by the relative size of intermediate input-output coefficients. The comparison of coefficients can be made across intermediate inputs within a production activity, or by comparing an input's coefficient across industries or countries. An activity is intensive in an intermediate input if its input-output coefficient for that input is higher than for other intermediate inputs, higher for that input compared to other production activities, or higher for that input compared to the same activity in other countries.

Isocost describes all combinations of inputs that can be purchased for the same cost.

Isoquant describes all technologically feasible combinations of inputs that can be used to produce the same level of output.

Isorevenue line shows all combinations of outputs that generate the same amount of revenue for the producer.

Large country's world prices for its imports and exports are influenced by its export and import quantities.

Law of Demand states that demand for a good will rise (fall) when its price falls (rises).

Leontief fixed-proportions production function assumes that all inputs must be used in fixed proportions to output.

Long run is a post-shock adjustment period that is sufficiently long that factors are fully mobile across production activities, and factor endowments and factor productivity may change.

Luxury good has an income elasticity of demand that is greater than one.

Macro-micro model provides the endogenous, macroeconomic results from a CGE model (the macro model) as the exogenous inputs into a microeconomic model with large numbers of households or firms.

Marginal product is the addition to output from an additional unit of an input, holding other inputs constant.

Marginal rate of substitution is the rate at which the consumer is willing to trade off a unit of one good for one unit of the other good.

Marginal rate of transformation is the rate at which producers can substitute production for exports with production for the domestic market in a given level of output, or the rate at which workers can transform from employment in one industry to employment in another industry in a given size of labor force.

Marginal utility is the addition to utility or consumer satisfaction from an additional unit of consumption.

Marginal welfare burden is the change in national welfare due to a very small – marginal – change in an existing tax.

Medium run is a post-shock adjustment period sufficiently long that factors are fully mobile across production activities, but too short for long-run changes in factor accumulation or productivity to take place.

Model closure is the modeler's decision as to which variables are exogenous and which are endogenous.

Multi-country model contains two or more countries (or regions) whose economies and economic behavior are described in detail and which are linked through trade and, sometimes, capital and labor flows.

Multilateralism is the reduction of trade barriers among all countries.

Necessity good has an income elasticity of demand that is less than one.

Nested production function: *see* production function, nested.

Net substitute: Two goods are net substitutes if a decline (rise) in the price of X relative to Y causes an increase (decrease) in the quantity ratio of X to Y, holding output or utility constant.

Nonhomothetic utility function assumes the income elasticity of demand does not equal one so that the percentage change in quantity demanded changes by less than (the income elasticity is less than one) or more than (the income elasticity exceeds one) the percentage change in income.

Non-tariff measure (NTM) is a policy measure other than an import tariff that can potentially have an economic effect on international trade in goods by changing the quantities traded, their prices, or both.

Normal good has a positive income elasticity of demand. Demand for a normal good increases when income rises.

Numeraire is a price that is fixed at its base value and serves as the standard of value against which all other prices in the model can be measured.

Outcome-based regulation allows producers to choose the least-cost means of achieving the regulatory goal.

Output effect on factor demand is the change in demand for all inputs by the same proportion as the change in output, holding input price ratios constant.

Output effect of a regulation is the reduction in production of the externality that occurs when compliance costs lead to higher output prices and lower consumer demand and production.

Parameters in a CGE model include elasticity parameters, calibrated shift, and share parameters used in production and consumption functions, and calculated tax rates.

Partial equilibrium model is a system of mathematical equations that describe the economic motives and behaviors in the market for one good, or for one type of economic agent, such as consumers, holding prices and quantities in the rest of the economy constant.

Preferential trade agreement reduces trade barriers among pact members but maintains barriers against non-members.

Price transmission describes the percentage change in a domestic price given a percentage change in another price.

Primary factor inputs: *see* factor.

Process-based regulation requires an industry to purchase a specific input or technology, or practice a mandated technique.

Product transformation curve plots all possible combinations of two goods that can be produced with a given quantity of productive resources.

Production function defines the technology, or physical production process, by which intermediate inputs are transformed by machinery and workers into a product.

Production function, nested separates the production process into smaller production processes that are "nested" within the larger process of producing the final product. Each nest has its own production function.

Quasi-homothetic preferences describe fixed minimum consumption requirements and homothetic preferences for discretionary consumption goods.

Rational expectations describe producers and consumers who anticipate and take into account prices and income in all time periods as they make their current decisions.

Real consumption measure of welfare: *see* welfare, real consumption

Real exchange rate: *see* exchange rate, real.

Regional household is a macroeconomic account that aggregates total national income from factor earnings and taxes, and allocates the income to private consumption, government, and savings.

Regulation is a "command and control" approach in which the government directly mandates certain behavior and enforces it with undesirable outcomes.

Rent (economic) from an NTM is measured by the price wedge between the domestic and world prices multiplied by the quantity produced or traded.

Rybczynki theorem posits that an increase in the quantity of one factor will lead to an absolute increase in the production of the good that uses that factor intensively, and an absolute decrease in production of the good that does not use it intensively, holding world prices constant.

Second-best is the most efficient outcome attainable if there is an existing distortion in another market due to a tax, a market failure, or other type of economic constraint.

Sector-specific factor: *see* immobile factor.

Sensitivity analysis is a check on the robustness of model results to alternative values of elasticity parameters or sizes of shocks.

Sets are the domains over which parameters, variables, and equations are defined.

Share parameter is a calibrated parameter that describes a share, such as a factor share in value added, or imported and domestic shares in consumption.

Shift parameter is a calibrated parameter in the production function that describes the level of input productivity.

Short-run equilibrium describes a post-shock adjustment period that is short enough that at least one factor of production, usually capital, remains immobile, and no long-term changes in factor endowments or productivity occur.

Single-country model describes only one country in detail and summarizes the rest-of-world economy as import demand and export supply functions.

Small country's world prices for its imports and exports are determined by world price levels and are independent of its export and import quantities.

Social Accounting Matrix is a square matrix whose columns and rows describe transactions among buyers and sellers in the circular flow of income and spending in an economy in a time period.

Static model describes an economy's equilibria before and after a shock, holding factor supplies constant, and does not depict the adjustment path.

Stochastic CGE model accounts for randomness in the economy and solves for the mean values and probability distributions of the endogenous variables.

Stolper-Samuelson theorem posits that an increase in the world price of a good leads to a rise in the price of the factor used intensively in its production, and a decline in the price of the other factor.

Structure refers to the shares in economic activity, including industrial composition of output, the commodity composition of demand and trade, and shares of each factor in employment and earnings.

Structure table uses the microeconomic data in the SAM to describe the economy in terms of shares (e.g., shares of each commodity in households' consumption).

Substitute goods or factors are items for which the producer or consumer is willing to trade off more of one for less of the other as their relative prices change.

Substitution effect is the change in the ratio of inputs in production or in consumption as relative prices change, at constant output or utility levels.

Tax, ad valorem is levied as a percentage of the value of goods or services.

Tax, direct is levied on factors or individuals; its direct burden cannot be shifted to other agents.

Tax, export is levied on exports.

Tax, factor use is levied on producers based on their employment of factors of production.

Tax incidence describes how the direct burden of indirect taxes is shared among buyers and sellers after prices and quantities adjust.

Tax, income is a direct tax paid by factors or households on the basis of income earned.

Tax, indirect is levied on the production or purchase of goods or factors; its direct burden can be shifted from the entity that pays the tax onto someone else through a change in price of the good or factor.

Tax, lump sum is a fixed tax liability that does not depend on income, wealth, or level of consumption or production.

Tax, production is levied on producers based on their output.

Tax, sales is levied on purchases of goods and services used as intermediate inputs or in final demand.

Tax, specific is levied per quantity unit.

Technology tree: *see* nested production function.

Terms of trade is the ratio of the world (*fob*) price of a country's export good(s) relative to the *fob* price of its import good(s).

Total factor productivity (TFP) is the output level per unit of aggregate factor input.

Trade creation is the shift in the quantity of production within a preferential trade area from a high-cost producer to lower-cost members, plus the expansion of the quantity of consumption as prices within the union fall.

Trade diversion is the shift in the quantity of imports from lower-cost countries outside of a preferential trade agreement to higher-cost producers within the trade pact.

Trade efficiency is a measure of the use of resources used in the transport of goods from the exporting country to the importing country.

Trade margins are the insurance plus freight charges incurred when goods are shipped by air, sea, or overland from the exporting country to the importing country.

Upstream industries are the production activities that produce goods that are used as intermediate inputs into other, "downstream" industries.

Utility function describes how commodities can be combined, according to the tastes and preferences of consumers, to generate consumer utility or satisfaction.

Value-added includes factor input costs and tax payments by activities in the production of goods and services.

Value-added production function describes the stage of the production process in which producers choose the most efficient ratios of factors in a given value-added bundle.

Welfare, equivalent variation is a money-metric measure of the value to the consumer of the price changes due to a shock. It is calculated as the difference in income required to achieve the new versus the initial levels of utility when goods are valued at base year prices.

Welfare, real consumption is a money-metric measure of the value to the consumer of the price changes due to a shock. It is calculated as the difference in income required to buy the new basket of goods versus the initial basket of goods when both baskets are valued at base year prices.

Practice and Review Answer Key

Chapter 1

1. P = 4, QO = QD = 4.
2. P = 5, QO = QD = 6

Table 1.2. *Partial versus General Equilibrium Analysis (answer key)*

	Bicycle Equilibrium Price Is Higher/Lower than $1.50	Bicycle Equilibrium Quantity Is Greater/Less than 15	Which Curve Shifts and in Which Direction?
Increase in price of rubber tires	**$1.50**	**15**	**Supply (S^1)shifts upward/left**
Bicycle workers accept lower wages	lower	greater	*Supply (S^2)shifts downward/right*
Consumer demand shifts to imported bicycles	lower	less than	*Demand shifts downward/left*
Decline in exports causes depreciation and higher imported input costs	higher	less than	*Supply (S^2)shifts upward/left*
Bicycle seat price falls due to fall in demand from bicycle producers	lower	greater than	*Supply (S^2)shifts downward/right*

Chapter 2

1. P_i, $P_{\text{“manufactures”}}$
2. Quantity of agricultural imports by Brazil from the United States.
3. D.1. Equilibrium of D^2 at S^1 has a higher equilibrium price and a lower quantity than equilibrium of S^2 and D^2.

D.2. The supply curve is more elastic when (1) factor substitution elasticity is larger, (2) factor mobility elasticity is larger in absolute value and (3) export transformation is larger in absolute value.

4. Equilibrium at S2 and D1 has a lower equilibrium price and quantity than equilibrium at S2 and D2. Demand for the domestic good is more elastic when (1) own price and commodity substitution elasticities are larger and (2) import substitution elasticities are larger.

Table 2.3. *Normalized Prices and Quantities of Apples (answer key)*

	Base Values			50% Change in Quantity			
	Price	Quantity	Value	Price	Quantity	Value	% Change in Value
Actual	2	12	24	2	18	36	50
Normalized	1	24	24	1	36	36	50

Table 2.4. *Calculating the U.S. Consumer Import Price of Corn (answer key)*

	France	Germany	South Africa
Exporter's market share of U.S. corn imports	50	25	25
Exporter bilateral *fob* export price (PFOB)	\$1.25	\$0.85	\$1.90
Trade margin	\$0.25	\$0.15	\$0.10
U.S. bilateral *cif* import price (PCIF)	\$1.50	\$1.00	\$2.00
Tariff cost	\$.50	\$.40	\$.10
Bilateral domestic price of import (PMS)	\$2.00	\$1.40	\$2.10
Trade-weighted domestic price of import (import share * PMS)	.50 * \$2.00 = \$1.00	.25 * \$1.40 = \$0.35	.25 * \$2.10 = \$0.53
Bilateral domestic price of import (PIM) (sum of weighted PMS's)	\$1.00 + \$0.35 + \$.53 = \$1.88		
Sales tax cost	\$0.12		
U.S. consumer import price (PM)	\$2.00		

7. The price transmission elasticity of the French bilateral *fob* export price with respect to the U.S. consumer import price 10/50 = .20.

Chapter 3

1. a. Mfg. gross output = \$6,657 billion
   b. Mfg. value added = factor payments + all taxes and subsidies = \$2,323
   c. Mfg. GDP = Mfg. value added + taxes paid on mfg. imports and exports, and mfg. sales taxes paid by households, government and investors = \$2,547
   d. Mfg. intermediate input costs = \$4,333

f. Total labor costs in services = factor payment + factor tax = \$7,820
g. Labor's share of industry costs in services = (\$6,797 + \$1,023) / \$18,212 = 43%.

2. a. Agr. import cost = (imports + tariff + trade margin) = \$34 billion
b. Agr. domestic variety = \$326
c. Agr. total supply of composite commodity = \$360
d. Agr. exports = \$52
e. Import share of private household's agr. consumption = import cost/total household agricultural consumption = (\$13 + \$1) /(\$13 + \$53 + \$1+ \$2) ∗ 100 = 20%.
f. (52/326) ∗ 100 = 16%

Chapter 4

1. a. Agriculture: C = 53, G = 0, I = 0, E = 52.
b. Services: C = 7,742, G = 2,258, I = 1,604, E = 345 + 28.
2. Agr = (53+2)/9,949 = .54; MFG = (1,355 + 137)/9,949 = 15; SER = (7,742 + 51)/9,949 = 78.3.
3. A homothetic utility function assumes that consumers will change their demand for all goods and services by the same proportion as the change in income. A non-homothetic utility function can describe goods as luxuries or necessities, for which growth in demand will not change by the same proportion as income. The main differences between the two utility functions in an analysis of economic growth is that the nonhomothetic function will lead to higher demand for luxury goods and lower demand for necessities relative to the change in income, which will cause a shift in production and trade toward luxury products. The homothetic function will lead to a more equi-proportionate growth in demand, production, and trade for each good.
4. A large value for the Armington parameter describes a flatter isoquant, becoming linear as the parameter value approaches infinity. When the parameter value becomes smaller, the isoquant becomes more curved. In the limit, the parameter value approaches zero and the curve is L-shaped. When the tariff is removed, a larger parameter causes a larger change in domestic-import quantity ratios.
5. The real consumption welfare change in welfare is \$6. The price changes have increased national welfare.

Table 4.8. *Practice and Review Calculation of the Real Consumption Welfare Measure (answer key)*

	Initial Price	Initial Quantity	New Quantity	Cost of Initial Quantity at Initial Prices	Cost of New Quantity at Initial Prices
Apples	\$1.00	5	6	\$5.00	\$6.00
Oranges	\$1.00	5	4	\$5.00	\$4.00
Candy bars	\$1.00	2	8	\$2.00	\$8.00
Total	–	–	–	\$12.00	\$18.00

Chapter 5

1. Total intermediates: 4,335

   Total factor payments: 2,010
   Total taxes: 315
   Value-added: 2,325
   Gross output: 6,660 (with rounding error)

Table 5.7. *Input-Output Coefficients (answer key)*

	Inputs into Production		Input-Output Coefficients	
	Manufacturing	Services	Mfg.	Services
Labor	12	12	.24	.12
Capital	8	18	.16	.18
Manufacturing	10	50	.20	.50
Services	20	20	.40	.20
Gross value of output	50	100	1.00	1.00

2. a. Mfg. is labor intensive.
   b. Services is capital intensive.
   c. Manufacturing is the most service-intensive production activity in the economy.
   d. Upstream role: manufacturing is an important input supplier of intermediate inputs to services, accounting most of its intermediate input requirements. Downstream role: manufacturing depends on services, which accounts for most of its intermediate input requirements.
3. See Figure 5.3. Lower wage costs relative to the price of capital rotates the isocost curve from C1 to C2. The labor/capital ratio rises from L^1/K^1 to L^2/K^2 in the production of value-added bundle QVA^1.
4. This CGE model probably has a Leontief-fixed proportion production function because there is no substitution among intermediates, and demands for intermediate inputs change by the same proportion as output. The model has a value-added production function that allows substitution among factors because the factor input ratio changes. Because production becomes more labor intensive, wages must have fallen relative to rents.

Chapter 6

1. Figure 2.1 describes the relatively elastic supply curve of an industry with a mobile factor and the relatively inelastic supply curve of an industry with an immobile, sector-specific factor. A demand shock leads to a larger quantity effect and smaller price effect for an industry when factors are mobile compared to when factors are immobile.
2. Assuming that the equipment is a capital input that is complementary to engineering labor in the production of computer chips, an increase in the supply of

engineers should increase demand for the equipment. The increase in the number of engineers shifts the demand curve for the capital good outward and results in a higher price and quantity for the equipment. You should advise the industry to support the training program.

3. Services is the most labor-intensive sector and the largest employer in the U.S. economy. A production subsidy that leads to an increase in services output is likely to increase wages relative to rents and cause all three sectors to become more capital-intensive.

Chapter 7

1. a. Televisions are capital intensive, and wine is labor intensive.
   b. Capital costs will fall and this will lower the costs of production of TV's more than of wine because capital accounts for a larger share of TV's production costs. Output of wine output will be greater than of TVs.
   c. Wine is relatively exportable, and televisions are relatively importable.
   d. An increase in production of the importable will reduce the country's demand for imports, so the world import price is likely to fall. A decrease in production of the exportable will decrease its supply of exports, so its world export price is likely to rise. This country's terms of trade will likely improve because its world export price will increase relative to its world import price.
2. The Dutch Disease model describes (1) resource endowment effects, (2) spending effects and 3) real exchange rate changes. The resource endowment effect describes resource competition by the expanding oil sector, which causes output in other industries to fall. The spending effect describes the increased demand for goods and services as incomes grow. Both effects lead to real exchange rate appreciation and increased import competition for Venezuela's industrial sector, and the potential for deindustrialization.
3. % change in U.S. world export price $= (.6 * 6) + (.4 * 4) = 5.2$
   % change in U.S. world (fob) import price $= (.8 * 4) + (.2 * 1) = 3.4$
   % change in U.S. terms of trade $= (5.2 - 3.4) = 1.8$. The U.S. terms of trade improves.

Chapter 8

1. In the graph, the import with a more price-elastic demand is described by a flatter demand curve and a larger excess burden than the import with price-inelastic demand. The welfare cost of the tariff will be smaller for the less elastic import.
2. For both sectors, the factor use tax is 15.1% for labor and 3.3% for capital. Because the factor use taxes are the same in both industries, they do not distort factor allocation between them. The taxes make labor expensive relative to capital and create an incentive for both industries to become more capital intensive.
3. See Text Figure 8.4.
4. a. $\$200,000/\$1,000000 * 100 = 20$ cents.

b. The government must earn a return of 120% on its project, or the cost in terms of tax dollars spent and inefficiencies linked to the taxes will be greater than the project's benefits.
c. The marginal excess burden will be smaller if the tax is levied on price-inelastic goods, because distortions of the student's consumption basket will be smaller.
d. The subsidized textbook industry is likely producing quantities that are greater than is economically efficient, given the nation's resources and preferences. A sales tax in the bookstore will likely reduce demand for and output of textbooks, and reduce the inefficiency linked to the textbook subsidy.

5. Members of a free trade area reduce or eliminate tariffs on each other's goods but maintain their own tariffs against non-members. See Figure 8.7 for graphs that depict trade creation effects. Important variables to review in describing the welfare impacts of the PTA are related to the variables in the graphs: changes in the real value (quantities) of imports, allocative efficiency welfare gains from import tariff removal that describe the efficiency triangles in the graphs, and terms-of-trade impacts that describe the terms-of-trade effects in the graph.

Chapter 9

1. Deterioration of the strawberry shipment can be modeled as an iceberg trade cost, which is a loss in trade efficiency. A graph of this problem looks like Figure 9.2.
2. A graph of this problem looks like Figure 9.3. The net effect of the regulation is to lower output and charge a higher price, resulting in an allocative efficiency loss of area $f + c$ and a societal gain of area $f + c + g$ due to the reduction in output; the figure describes a net benefit of area g from reducing production of the externality. The allocative efficiency effect in model results corresponds to area $f + c$. A standard CGE model does not measure the benefits shown by area $c + f + g$.
3. A process-based regulation requires an industry to purchase a specific input or technology, or practice a mandated technique. If it increases production costs and price, it will lead to a negative output effect. An outcome-based regulation allows producers to find the least costly way of achieving the regulatory goal. In addition to the output effect, it may include substituting among inputs or technological innovation that reduces the externality per unit of output. A regulation's direct cost is the loss in allocative efficiency. Its indirect costs are the changes in total production of externalities resulting from changes in industry size and composition, second-best efficiency effects, and terms-of-trade changes. A standard CGE model can examine process-based regulations' direct and indirect costs.

Model Exercise Answer Key

Model Exercise 2

B.2 REG = US, ROW are the regions in the database
B.3 TRAD_COM = AGR, MFG, and SER are the sectors in the database
B.4 END_COM = LAND, LABOR and CAPITAL are the factors of production in the database
C. An error message: "You cannot view more than two dimensions."
D. INCPAR("USA", "SER") = 1.04.

Table ME 2.1. *Elasticity Parameters for U.S. Agriculture (answer key)*

Elasticity	Value
Supply parameters	
Factor substitution (ESUBVA)	0.25
Intermediate input substitution (ESUBT)	0.00
Demand parameters	
Consumer income (INCPAR)	0.17
Consumer substitution (SUBPAR)	0.82
Import substitution (imports v. domestic good) (ESUBD)	2.38
Import substitution (among trade partners) (ESUBM)	4.80

Table ME 2.2. *Tax Rates for U.S. Agriculture (answer key)*

Tax rate	Name	Value
rTO	% ad valorem rate, output (or income) tax in region *r*	–0.24
rTF	% ad valorem rate, taxes on primary factors	–4.11
rTPD	% ad valorem rate, private domestic consumption taxes	4.48
rTPI	% ad valorem rate, private import consumption taxes	6.19
rTGD	% ad valorem rate, government domestic purchases taxes	0.00
rTGI	% ad valorem rate, government import purchases taxes	0.00
rTFD	% ad valorem rate, taxes on firms' domestic purchases	–3.95
rTFI	% ad valorem rate, taxes on firms' import purchases	–4.11
rTXS	% ad valorem rate, export taxes by destination	–0.00
rTMS	% ad valorem rate, import taxes by source	1.56

F.1. Variable definitions:

pm = market price of commodity *i* in region *r*
pop = regional population
qfe = demand for endowment *i* for use in industry j in region *r*
qiw = aggregate imports of *i* in region s, *cif* weights

F.2. Population is exogenous and all the rest of the variables listed in F.1 are endogenous.

Model Exercise 3

C2. *to* is defined as the percent *ad valorem* output or income subsidy in region *r*.
C3. –1.05
C4. a tax

Table ME 3.2. *Results of a 10 percent Production Subsidy to U.S. Manufacturing, with Different Elasticities and Closures (answer key)*

	Definition of Variable	Base Results	High Factor Substitution Elasticity in MFG	Unemployment Closure
qo(“MFG”, “USA”)	Industry output of MFG in USA	4.093	4.102	25.555
qo(“MFG”, “ROW”)	Industry output of MFG in ROW	0.205	0.203	1.358
qfe(“LABOR”, “MFG”, “USA”)	Demand for LABOR in MFG in USA	4.098	4.126	35.236

Source: GTAP model, GTAP v.8.0 U.S. 3×3 database.

Table ME 3.3. *Welfare Decomposition of a 10% Production Subsidy to U.S. Manufacturing (answer key)*

Resource Allocation Effect	Endowment Effect	Technical Change	Population Growth	Terms of Trade	Investment–Savings Terms of Trade	Preference Change	Total
1 alloc_A1	2 endw_B1	3 tech_C1	4 pop_D1	5 tot_E1	6 IS_F1	7 pref_G1	
12,721	0	0	0	63,055	93,240	0	169,016

Source: GTAP model, U.S. 3×3 v.8.0 database.

a. *qo*(“MFG”, “USA”) = 4.09
b. Mean = 4.08
c. Standard deviation = 0.05

Table ME 3.5. *Confidence Intervals for the Manufacturing Output Quantity Result with a 100% Variation in the Factor Substitution Elasticity (answer key)*

Confidence Interval	Mean (X)	Standard Deviation (sd)	Standard Deviation Multiplier (K)	Upper Limit (X + sdK)	Lower Limit (X − sdK)
75%	4.08	0.05	2	4.18	3.98
88.9%	4.08	0.05	3	4.23	3.93
95%	4.08	0.05	4.47	4.30	3.86
99%	4.08	0.05	10	4.58	3.58

Model Exercise 4

Table ME 4.1. *Elasticities in Two Scenarios of a 50% Increase in the World Agricultural Price (answer key)*

	Scenario 1		Scenario 2	
Elasticities	INCPAR	SUBPAR	INCPAR	SUBPAR
Agriculture	0.17	0.82	1	0
Manufacturing	0.88	0.20	1	0
Services	1.04	0.17	1	0

Table ME 4.2. *Household Budget Shares (answer key)*

	Base	Scenario 1	Scenario 2
Agriculture	.007	.008	.007
Manufacturing	.205	.205	.205
Services	.788	.787	.788

Table ME 4.3. *Effects of a 50% Increase in the World Price of Agriculture (% change from base) (answer key)*

	World price	Consumer Price	Consumer Composite Commodity Quantity	Consumer Domestic Quantity	Consumer Import Quantity	Production Quantity
GTAP variable name	*pxwcom*	*Pp*	*qp*	*qpd*	*Qpm*	*qo*
CDE utility						
Agric.	50.03	25.62	−4.50	7.52	−53.35	30.13
Mfg.	0.64	1.35	−0.07	−1.27	3.28	−2.16
Services	−2.75	0.96	0.25	0.20	8.40	0.04
Cobb-Douglas						
Agr.	40.99	19.66	−18.30	−7.50	−62.2	21.56
Mfg.	0.65	1.27	0.09	−0.96	2.98	−1.84
Services	−2.14	1.07	0.30	0.25	7.33	0.09

1. The utility functions assume negative own-price elasticities. With income constant, as the price rises, demand should fall. In the CGE model, the demand quantity falls in both scenarios.
2. The CDE demand system is nonhomothetic. AGR is a necessity good, SER is a luxury good, and MFG is a necessity that is more responsive to income changes than AGR. The CD function in such a manner that, holding prices constant, demand quantities of all three goods change by the same proportion as income.
3. Elasticity of substitution of AGR/MFG: $(-18.3 - 0.09)/(19.66 - 1.27) = -1$.
4. The CDE demand system allows flexible budget shares. In the CDE scenario, the agricultural budget share rises because the AGR price rises, and the decline in quantity demanded falls by proportionately less than the price increase. The CD utility function imposes fixed budget shares, so the change in quantity exactly offsets percentage changes in price and income.
5. Both scenarios describe a substantial decline in imports and increased consumer demand for the domestic variety of AGR. This causes U.S. agricultural output to increase. Higher agricultural output will exert a pull on the productive resources used in MFG and SER, so their output will decline.
6. The Armington assumption implies that consumers differentiate goods by country of origin, and consumers' willingness to substitute between imports and domestic varieties is governed by an import substitution elasticity. Both experiments assume an import-domestic substitution elasticities for AGR of 2.38. As the relative price of the imported AGR rises, the ratio of imports to the domestic variety falls in the household consumption basket.

Model Exercise 5

1. See the technology tree in Figure 5.1. Your tree will look similar, with a value-added nest containing capital, labor, and land, governed by the default factor substitution elasticity and an intermediate input bundle that contains AGR, MFG, and SER inputs, governed by an intermediate input substitution elasticity of zero. The two bundles are combined to produce AGR governed by an aggregate input substitution elasticity of zero.
2. Price changes could lead to factor substitution in the CGE model, but no substitution among intermediates or between the intermediate and value-added bundles.
3. AGR becomes more land intensive and less intensive in the use of labor and capital. This reaults in a decline in the marginal product of land relative to the marginal products of labor and capital; therefore, land rents fall relative to wage and capital rents. Intermediate input-output ratios are unchanged, consistent with the Leontief intermediate input technology in the U.S. 3×3 model.
4. The output subsidy in U.S. agriculture is actually a tax, and its removal leads to higher agricultural output and exports and a lower U.S. world price. The loss of the land subsidy effect has little impact except on land rents, because land is a factor that is specific to, and only used in, agriculture. The elimination of input subsidies has the dominant impact and leads to lower U.S. output and higher world prices.

Table ME 5.1. *Base and Updated Subsidy Rates in U.S. Agriculture (answer key)*

	Base Rate	Updated Rate
Production (output) subsidy rto ("AGR", "USA") (negative value = tax)	–0.24	0
Tax on land use rtf ("LAND", "AGR", "USA") (negative value = subsidy)	–4.11	0
Tax on domestic intermediate input rtfd ("AGR", "AGR", "USA") (negative value = subsidy)	–4.0	0
Tax on imported intermediate input rtfi ("AGR", "AGR", "USA") (negative value = subsidy)	–4.1	0

Table ME 5.2. *Effects of U.S. Agricultural Subsidy Elimination (% change from base) (answer key)*

		Base ESUBVA Factor Substitution Elasticity				ESUBVA = 12
			Subtotals			
	Variable Name in GTAP	TOTAL	Output Tax Effect	Land Subsidy Effect	Intermediate Input Tax/ Subsidy Effect	TOTAL
Agricultural output quantity	*qo*(AGR,USA)	0.87	0.15	0.00	– 1.02	– 1.37
Agricultural producer price	*ps*(AGR,USA)	1.29	0.07	0.00	1.22	1.80
Land rent	*ps*(LAND,USA)	– 8.57	0.77	– 4.01	– 5.32	– 4.35
Labor wage	*ps*(LABOR,USA)	– 0.05	0.01	0.00	– 0.06	– 0.09
Capital rent	*ps*(CAPITAL,USA)	– 0.06	0.01	0.00	– 0.07	– 0.09
Household consumption	*qp*(AGR,USA)	– 0.16	0.03	0.00	– 0.19	– 0.24
Export quantity	*qxw*(AGR,USA)	– 3.53	0.59	0.00	– 4.12	– 5.57
Export price	*pxw*(AGR,USA)	1.05	– 0.18	0.00	1.22	1.55

Policy makers may want to select reforms with different impacts, or phase them all in together, knowing that they have offsetting impacts on AGR.

5. Supply response becomes more elastic as the factor substitution elasticity gets larger.
6. Food prices will rise, but agriculture accounts for only 1% of U.S. household spending, so U.S. consumers are not likely to be substantially affected by an agricultural reform program.

Table ME 5.3. *Change in Input-Output Coefficients due to U.S. Agricultural Policy Reform (% change from base)*

Output and Inputs	Output and Input Quantities	Change in Input-Output Coefficients (*qfe-qo*) or (*qf-qo*)
AGR output (*qo*)	–0.87	Not applicable
Land (*qfe*)	0.0	0.87
Labor (*qfe*)	–1.16	–0.27
Capital (*qfe*)	–1.16	–0.27
AGR intermediate (*qf*)	–0.87	0.0
MFG intermediate (*qf*)	–0.87	0.0
SER intermediate (*qf*)	–0.87	0.0

8. Land cannot be employed elsewhere, so a change in land use tax has no effect on the quantity of land demanded, and therefore on AGR output levels. It directly increases the return to land by the full amount of the subsidy.

Model Exercise 6

Table ME 6.1. *Effects of a 10% Increase in the U.S. Supply of Unskilled Labor (answer key)*

Factor Price (*pfe*)			Demand for Labor (*qfe*) Unskilled	Skilled	Output (*qo*)
BORJAS – 10% increase in unskilled labor supply with high factor substitution					
Unskilled	−1.23	Agriculture	10.54	0.5	3.95
Skilled labor	−0.44	Manufactures	10.10	0.10	4.57
Capital	−0.44	Services	9.97	−0.02	3.91
OTTA1 – 10% increase in unskilled labor supply with low factor substitution					
Skilled	−9.98	Agriculture	1.15	−2.75	−1.42
Skilled labor	10.30	Manufactures	6.48	−3.49	0.83
Capital	9.72	Service	10.94	0.55	4.48
OTTA2 – 10% increase in unskilled labor, 6 percent increase in capital, low factor substitution					
Unskilled	−8.42	Agriculture	7.74	3.72	6.61
Skilled labor	10.76	Manufactures	9.86	0.68	6.83
Capital	−1.34	Services	6.15	−0.11	5.27

1. See Figures 6.2a and 6.2b in Chapter 6.
2. Change the factor substitution elasticities. A larger parameter value describes a more flexible production technology, with a relatively large substitution in factor input quantities given a percentage change in the inverse of their relative prices.
3. When firm technologies are assumed to allow easy substitution among factors, an increase in supply and fall in the wage of unskilled workers will lead to a substitution that intensifies their use in the production process and a fall in demand for and prices of the other two factors.

Table ME 6.2. *Real GDP Effects of a 10% Increase in U.S. Unskilled Labor Supply*

Scenario	% Change in Real GDP
BORJAS	4.01
OTTA1	3.85
OTTA2	5.54

4. See Figures 6.2c and 6.2d in Chapter 6.
5. Producers must hire more skilled labor and capital to complement their increased use of unskilled workers, which increases demand for and prices of skilled labor and capital.
6. An increase in the capital stock will shift the demand curves for both unskilled and skilled labor outward, if factors are assumed to be relatively complementary. Wages of both labor types will increase relative to the results of OTTO1.
7. The price of capital falls because the supply of capital increases.
8. Real GDP grows because the endowment of productive resources grows. Comparing the identical shocks in BORJAS and OTTA1, real GDP growth is larger when the production technology is more flexible, allowing producers to better take advantage of an increase in an endowment and a fall in its price.

Model Exercise 7

Table ME 7.3. *Base Tax Rates in U.S. 3×3 Model (answer key)*

	Tax Rate					
	United States			Rest-of-World		
Tax type	Agr.	Mfg.	Services	Agr.	Mfg.	Services
Taxes on domestic intermediates used in agricultural production (rTFD)	−3.95	−0.59	−4.10	−6.51	−4.04	−4.99
Taxes on imported intermediates used in agricultural production (rTFI)	−4.11	−1.94	−4.49	−4.36	−2.81	−4.71
Export taxes (rTXS)	0.00	−0.29	0.00	0.03	−1.56	0.00
Import tariffs (rTMS)	1.56	1.23	0.00	6.36	2.87	0.00

Source: GTAP v.8.1.

1. The total world welfare effect is positive. The equivalent variation measures the income equivalent of the change in pre- and post-shock levels of utility, both valued at vase year prices.
2. The main source is the benefit to the United States from ROW's nonagricultural policy reforms. The main benefit to ROW is its own nonagricultural policy

Table ME 7.4 *Welfare Effects of Trade Liberalization by Region and by Policy, $U.S. Millions*

	Total	U.S. Agricultural Policy Reform	U.S. Nonagricultural Policy Reform	Rest-of-World Agricultural Policy Reform	Rest-of-World Nonagricultural Policy Reform
United States	6,801	−311	−9,183	2,202	14,093
ROW	32,413	−326	−10,415	1,477	20,826

Note: Welfare is an equivalent variation measure.
Source: GTAP model, GTAP v.8.1 U.S. 3×3 database.

Table ME 7.5 *Decomposition of the Total Welfare Effect, $U.S. Millions*

	Allocative Efficiency	Terms of Trade in Goods and Services	Terms of Trade in Savings-Investment	Total
United States	583	5,979	238	6,801
ROW	38,598	−5,948	−237	32,413
World	39,182	31	1	39,213

Note: Welfare is an equivalent variation measure.
Source: GTAP model, GTAP v.8.1 U.S. 3×3 database.

Table ME 7.6 *Decomposition of the Import Tax Welfare Effect ($U.S. Millions)*

	U.S.	Rest-of-World
U.S.	0	1,481
Rest-of-World	55	14,439
Total	551	15,920

Source: GTAP model, GTAP v.8.1 U.S. 3×3 database.

reforms. The dominating role for MFG reform relative to AGR reform differs from Anderson and Martin. A comparison of the differences between your initial tariff rates shows that the substantial reduction in AGR import tariffs since their 2005 study accounts for at least some of the differences in your results.

3. ROW-ROW import tariffs in MFG are relatively high and it is a larger sector than AGR. Reviewing initia tax rates for accuracy is as important as reviewing elasticities. The modeler can update the database to define alternative initial tax and tariff values.
4. Both regions benefit from efficiency gains; for the U.S. these are relatively small compared to terms-of-trade effects.
5. Terms-of-trade effects measure the price of a country's exports relative to its imports, the import-purchasing power of its exports. In this experiment, they are an important component of each country's total welfare effect. The effects on

USA and ROW offset each other, because in this two-region model, an increase in one country's import price is the same as an increase in the other's export price.

6. The import substitution elasticity has the most direct effect on terms of trade because it influences the quantities of imports demanded when a country removes its tariffs, and therefore the supply quantity of its exports.
7. The toy 3×3 model's welfare effects are smaller because it is static, whereas theirs is a recursive dynamic model in which the economies have grown in size. Their model has more countries and commodities, and therefore more scope for efficiency gains. Also, import tariff rates are lower in your analysis than in theirs.

Model Exercise 8

10. a. Base tax revenue = 4,312,364
    b. Updated tax revenue = 4,350,106
    c. Change in government tax revenue = 37,742
13. a. EV = –821.6
    b. Mean = –820.6
    c. Standard deviation = 2.99

Table ME 8.4. *Welfare Effects of a 1% Increase in U.S. Taxes, $U.S. Millions (answer key)*

Allocative Efficiency	Endowment	Technology	Population	Terms of Trade in Goods and Services	Terms of Trade in Invest-Savings	Preference	Total Welfare Cost	Change in Government Tax Revenue	Welfare Cost (Cents) Per Dollar of Revenue
–270.0	0	0	0	–439.3	–112.3	0	–821.6	37,742	2.2

Source: GTAP model, GTAP v.8.1 U.S. 3×3 database.

Table ME 8.5. *Welfare Decomposition of the Allocative Efficiency Effect, $U.S. Million (answer key)*

Tax Type	Welfare Cost
Factor tax (pfattax)	−17.9
Production tax (prodtax)	−31.2
Input tax (inputtax – *tfd* + *tfm*)	−59.4
Private consumption tax (contax – *tpd* + *tpm*)	−117.0
Government tax (govtax – *tgd* + *tgm*)	0.0
Export tax (etax)	7.2
Import tax (mtax)	−51.8
Total	−270.0

Source: GTAP model, GTAP v.8.1 U.S. 3×3 database.

1. The direct burden is the increase in tax revenue of $37,741 million; its excess burden is an efficiency loss of $270 million.
2. Total welfare cost/Change in government tax revenue $*$ 100 = Marginal welfare burden $821.6/37{,}741 * 100 = 2.2\%$.

3. The marginal welfare cost is the welfare change per additional dollar of tax revenue. This loss is 2.2 cents per dollar, so the government should be advised that its project must return at least 102.2 percent of its costs, or welfare will decline.
4. Private consumption taxes have the most distorting effect and export taxes have the least effect.
5. Terms of trade for goods and services measure the price of exports relative to imports. It measures the import-purchasing power of exports, so it is included in the EV welfare measure. It is the most important component of the welfare changes due to the U.S. marginal tax increase.
6. The marginal welfare cost per dollar is substantially lower than the Ballard et al.'s finding. One reason is that the model has only three sectors. Taxes lead to allocative inefficiency by changing relative prices of goods such as groceries and autos. The more aggregated the model, the smaller the scope for a tax to change relative prices. Another reason is that the GTAP model does not capture dynamic effects of income taxes on savings and capital accumulation or the supply of labor.
7. 75% confidence range = –820.60 +/– 2 ∗ 2.99 = –826.6 to –814.6
   95% confidence range = –820.60 +/– 4.47 ∗ 2.99 = –829.5 to –811.8.

The negative sign of the EV result is robust with respect to the factor substitution elasticity.

Model Exercise 9

Table ME 9.2. *Percent Changes in Productivity and Real GDP in Baseline Scenario 2007–2050*

	U.S.	ROW
Total output productivity in AGR (*aoall*) 1/	28.09	36.15
Real GDP (*qgdp*) (solution value)	109.8	284.4

1/ Results for *aoreg* are reported on the Results page tab as "*ao*." Real GDP growth rates are the solution values in the baseline scenario with endogenous QGDP.
Source: GTAP CGE model, GTAP v8.8 US 3×3 database.

1. An integrated economic assessment begins with global climate models, which provide projected physical climate changes as inputs into biophysical models. Biophysical models describe the effects of these projections on biological processes including plant yields and human health. Economic models use these biological projections as shocks to economic models to explore the economic impacts of climate change.
3. You swap the endogenous real GDP variable with an exogenous productivity variable so that your baseline scenario can solve for the implicit level of productivity growth that is consistent with GDP projections. You restore the original closure and rerun the baseline scenario so that you can evaluate the accuracy of the solution values for productivity growth in replicating the targeted GDP growth. You

Table ME 9.3. *Economic Effects of Climate Change in 2050 (% changes 2007–2050)*

	United States			ROW		
	Without climate change	With climate change	Effect of climate change	Without climate change	With climate change	Effect of climate change
Real GDP (*qgdp*)	109.8	109.3	−0.5	284.4	281.7	−2.7
Agricultural output (*qo*)	53.1	53.4	0.3	69.4	68.9	−0.5
Agricultural producer price (*ps*)	−23.3	−9.7	13.5	−11.0	4.0	15.0
Agricultural private consumption (*qpd*)	48.8	43.1	−5.7	57.4	52.5	−4.9
Agricultural consumer price (*pp*)	−21.9	−8.5	13.4	−11.6	3.1	14.7
Agricultural exports (*qxw*)	237.0	237.9	0.9	63.5	66.7	3.2
Agricultural imports (*qiw*)	2.7	7.0	4.3	99.0	101.7	2.7
Import share of agricultural consumption (*qiw-qpd*)	−46.1	−36.1	10	41.6	49.2	7.6
Export share of agricultural production (*qxw-qo*)	183.9	184.5	0.6	−5.9	−2.2	3.7

Source: GTAP CGE model, GTAP v8.1 US 3×3 database.

use the original closure in both the baseline and climate change scenarios so that the only difference between the two scenarios is the climate change shock.

4. Exogenous adjustments to climate change in this experiment are the growth in land area and decline in agricultural yields. Endogenous adjustments are the changes in production, consumption, and trade.
7. Given the importance of trade and production as adjustment mechanisms, factor substitution and import substitution elasticities should be subjected to sensitivity analysis.

Model Exercise 10

1. INCPAR is a parameter related to the income elasticity of demand, which describes the percentage change in quantity demanded given a percentage change in income. The model experiments introduce long-term income growth. Reducing ROW's INCPAR means that the same growth in income will result in a smaller increase in its consumer demand for tobacco.
2. The INCPAR for tobacco and AG/MFG are less than one, and that for services is greater than one. All else equal, this means that demand for tobacco and AG/MFG will increase by proportionately less than the increase in income, whereas consumption of services will increase by proportionately more than the change in income. Therefore, the services budget share are expected to expand while the shares of tobacco and AG/MFG decline in both scenarios.
3. Given consumer preferences for services as incomes grow, all else being equal, services production will increase by proportionately more than other industries as their economies grow. However, other factors also influence output.

4. Antismoking preferences will cause the equilibrium quantities and price at B to be lower than at A. Verify this result in your model by comparing percent changes in tobacco price and output quantities in the two experiments.
5. The share of tobacco value added in both countries' GDP is less than 1 percent, so economy-wide effects, such as effects on production in other industries, employment, and macrovariables such as the wage and exchange rate, are likely to be minimal.

Table ME 10.2. *Share of Tobacco Value Added in GDP*

	USA	ROW
Percent share of tobacco value added in GDP	0.34	0.61

Source: GTAP v.8.1 3×3 tobacco model database.

Table ME 10.3. *Base and Updated INCPAR Parameter Values (answer key)*

	Base Parameter Values		Updated Parameter Values
	USA	ROW	ROW only
Tobacco	0.63	0.58	0.1
Agr/Mfg	0.87	0.81	*No change*
Services	1.04	1.13	*No change*

Source: GTAP model and GTAP v.8.1 3×3 tobacco model database.

Table ME 10.4. *Private Household Budget Shares under Alternative Scenarios (answer key)*

	Base		Income Growth		Income Growth with Row No-Smoking Preferences	
	USA	ROW	USA	ROW	USA	ROW
Tobacco	0.014	0.031	0.013	0.029	0.013	0.027
Agr./Mfg.	0.198	0.353	0.196	0.344	0.196	0.345
Services	0.788	0.615	0.791	0.627	0.791	0.628
Total	1.000	1.000	1.000	1.000	1.000	1.000

Source: GTAP model and GTAP v.8.1 3×3 tobacco model database.

Table ME 10.5. *Change in Rest-of-World Household Budget Shares (% change from base) (answer key)*

	Income Growth with No Preference Change	Income Growth with Anti-smoking Preference
Tobacco	−6.5	−12.9
Agr./Mfg.	−2.5	−2.3
Services	2.0	2.1

Source: GTAP model and GTAP v.8.1 3×3 tobacco model database.

Table ME 10.6. *Industry Output with and without Changes in ROW Smoking Preferences (% change from base)(answer key)*

	Income Growth		Income Growth with no-smoking Preferences	
	USA	ROW	USA	ROW
Tobacco	45.7	61.9	45.3	53.2
Agr/Mfg	36.9	66.4	36.8	66.5
Services	46.6	68.5	46.6	68.6

Source: GTAP model and v.8.1 3×3 tobacco model database.

Table ME 10.7. *Systematic Sensitivity Analysis of Preference Changes on Tobacco Quantities in the Rest-of-World (answer key)*

	Model Result	Mean	Standard Deviation	95% Confidence Interval	
				Upper	Lower
Production (*qo*)	53.19	53.19	0.72	56.41	49.97
Private consumption (*qp*)	47.23	47.23	1.03	51.83	42.63

Source: GTAP model and GTAP v.8.1 3×3 tobacco model database.

Model Exercise 11

1. An NTM is a policy measure other than an import tariff that can potentially have an economic effect on international trade in goods by changing the quantities traded, their prices, or both. It is typically represented in standard CGE models a rents accruing to exporters or importers or as an iceberg trade cost. Among the limitations of this approach is that rents and compliance costs are modeled as government revenue in a standard CGE model and that some NTMs may be demand-enhancing rather than supply-reducing.
2. Trade inefficiency describes the unproductive waste of resources in the transit of goods. An iceberg trade cost describes the lost resources in terms of the good that is transported. A real-world example might be inventory depreciation due to lost time at the border.
6. The two graphs should replicate Figures 8.9 and 8.10 in the text.

Table ME 11.3. *Define Import Tariff and Export Subsidy Rates for the Altertax and TTIP Experiments (answer key)*

	EU-25 bilateral trade policies					U.S. bilateral trade policies				
Formula	A	B	A + B	A + .75 ∗ B	.75 ∗ B	A	B	A + B	A + .75 ∗ B	.75 ∗ B
Model experiment	Base tariff and subsidy rates	EXP. 1: T-TIP with tariff removal only	Altertax update	EXP. 2: T-TIP with NTM reduction only	EXP. 3: “Ambitious” T-TIP scenario	Base tariff and subsidy rates	EXP. 1: T-TIP with tariff removal only	Altertax update	EXP. 2: T-TIP with NTM reduction only	EXP. 3: “Ambitious” T-TIP scenario
Import tariff	2007 rate	AVE of NTM	Import barriers including AVE of NTM	Import barriers after reducing NTMs only in T-TIP	Import barriers after eliminating tariffs and subsidies and reducing NTMs 25%	Base rate	AVE of NTM	Tax rate including AVE of NTM	Import barriers after removing NTMs only in T-TIP	Import barriers after eliminating tariffs and subsidies and reducing NTMs 25%
AGR	3.52	15.30	18.82	15.00	11.48	2.75	19.80	22.55	17.60	14.85
MFG	2.15	5.80	7.95	6.50	4.35	1.30	6.90	8.20	6.48	5.18
SER	0.00	2.30	2.30	1.73	1.73	0.00	2.40	2.40	1.80	1.80
Export subsidy	2007 rate	AVE of NTM	Subsidy rate including AVE of NTM	Export barriers after reducing NTMs only in T-TIP	Export barriers after T-TIP liberalization	Base rate	AVE of NTM	Subsidy rate including AVE of NTM	Export barriers after removing NTMs only in T-TIP	Export taxes after eliminating tariffs and subsidies and reducing NTMs 25%
AGR	0.12	–7.40	–7.28	–5.43	–5.55	0.00	–9.50	–9.50	–7.13	–7.13
MFG	0.01	–2.80	–2.79	–2.09	–2.10	–0.43	–3.30	–3.73	–2.91	–2.48
SER	0.00	–1.10	–1.10	–0.83	–0.83	0.00	–1.20	–1.20	–0.90	–0.90

Notes: Base import tariff and export subsidy rates are from GTAP v8.1. We use ECORYS’ estimated AVE for food and beverage as the AVE for AGR and their AVE for all goods as the AVE for the MFG sector. The 25% reduction in the AVE of NTMs is based on the ambitious T-TIP scenario defined in Francois et al. (2013).
Sources: Author calculations based on GTAP database v8.1 and ECORYS (2009).

Table ME 11.4. *Define the Changes in Trade Efficiency for T-TIP Experiments (answer key)*

	EU import barriers – trade efficiency of imports to the EU		U.S. import barriers – trade efficiency of imports to the United States	
Formula	A Base AVE of trade efficiency cost of NTMs	B = .25 ∗ A 25% increase in trade efficiency due to TTIP	A Base AVE of trade efficiency cost of NTMs	B = .25 ∗ A 25% increase in trade efficiency due to TTIP
AGR	34.1	8.53	44.0	11.00
MFG	12.9	3.23	15.2	3.80
SER	5.1	1.28	5.3	1.33

Notes: Base value of trade productivity is implicitly equal to one. We use ECORYS' estimated AVE for food and beverage as the AVE for AGR and their AVE for all goods as the AVE for the MFG sector. The 25% increase in trade efficiency is from the ambitious T-TIP scenario defined by Francois (2013).
Sources: Author calculations based on data in Francois et al. (2013).

Table ME 11.5. *Changes in real GDP (in percent) due to TTIP (answer key)*

		Stemming from	
Country	Total – ambitious scenario (TTIP3)	Tariff/subsidy elimination only (TTIP1)	NTM reduction only (TTIP2)
EU	0.16	0.02	0.14
United States	0.24	0.03	0.21

Note: Results report GTAP variable *qgdp*.
Source: GTAP model, GTAP v8.1 PTA3×3v2 database.

Table ME 11.6. *Percent Changes in Bilateral Traded Quantities due to TTIP (answer key)*

		Stemming from	
Country	Total bilateral export growth (ambitious scenario)	Tariff/subsidy elimination only	NTM reduction only
EU to United States			
Agriculture	113	11	91
Manufacturing	55	9	42
Services	6	1	6
United States to EU			
Agriculture	93	13	71
Manufacturing	62	17	39
Services	3	–1	5

Note: Results report GTAP variable $qxs_{i,r,s}$.
Source: GTAP model, GTAP v8.1 PTA3×3v2 database.

Table ME 11.7. *Welfare Impacts of Ambitious TTP (T-TIP Experiment 3) ($U.S. millions) answer key*

	Allocative efficiency	Technical efficiency	Termsof trade (goods)	Terms of trade (savings-investment	Total
EU	16,370	11,263	8,394	–1,965	34,062
United States	16,795	17,227	15,351	6,048	55,422
Rest of world	–4,523	0	–23,867	–4,118	–32,508

Source: GTAP model, GTAP v8.1 PTA3×3v2 database.

Table ME 11.8. *Trade Creation and Trade Diversion due to TTIP ($U.S. millions) (answer key)*

	EU imports from U.S.	EU imports from ROW
Agriculture	4,397	–908
Manufacturing.	122,482	1,865
Services	3,444	8,655
	U.S. imports from EU	**U.S. imports from ROW**
Agriculture	1,448	–369
Manufacturing	156,336	–59,354
Services	8,475	3,132

Note: Units are real values in 2007 dollars.
Source: GTAP model, GTAP v8.1 PTA3×3v2 database.

References

Anderson, Kym and Will Martin (2005). "Agricultural Trade Reform and the Doha Development Agenda," *The World Economy* 28(9): 1301–1327.
Andriamananjara, Soamiely, Michael Ferrantino, and Marinos Tsiagas (2003). "Alternative Approaches in Estimating the Economic Effects of Non-Tariff Measures: Results from Newly Quantified Measures." U.S. International Trade Commission, Office of Economics Working Paper 12-C. Accessed June 15, 2014 from http://ageconsearch.umn.edu/bitstream/15872/1/wp03012c.pdf.
Armington, Paul S. (1969). "A Theory of Demand for Products Distinguished by Place of Production." *IMF Staff Papers* 16: 159–178.
Arndt, Channing (2002). "HIV/AIDS and Macroeconomic Prospects for Mozambique: An Initial Assessment," Department of Agricultural Economics, Purdue University, West Lafayette, Indiana. Accessed December 4, 2009 from www.agecon.purdue.edu/staff/arndt/mozam_AIDS_dp.pdf.
Arndt, Channing, Thomas Hertel, Betina Demaranan, Karen Huff, and Robert McDougall (1997). "China in 2005: Implications for the Rest of the World," *Journal of Economic Integration* 12(4): 505–547.
Arndt, Channing and Kenneth R. Pearson (1998). *How to Carry Out Systematic Sensitivity Analysis via Gaussian Quadrature and GEMPACK*. GTAP Technical Paper No. 3. Center for Global Trade Analysis. West Lafayette, IN: Purdue University.
Auerbach, Alan J. and Laurence J. Kotlikoff (1987). *Dynamic Fiscal Policy*. Cambridge: Cambridge University Press.
Baldwin, Richard E. and Anthony J. Venables (1995). "Regional Economic Integration," in Gene M. Grossman and Kenneth Rogoff, eds., *Handbook of International Economics*, Vol. III. Amsterdam: Elsevier Science, B.V.
Balistreri, Edward J., Christine A. McDaniel, and Eina V. Wong (2003). "An Estimation of U.S. Industry-Level Capital-Labor Substitution," *The North American Journal of Economics and Finance* 14(3): 343–356.
Ballard, Charles L. and Don Fullerton (1992). "Distortionary Taxes and the Provision of Public Goods," *Journal of Economic Perspectives* 6(3): 117–131.
Ballard, Charles L., John B. Shoven, and John Whalley (1985). "General Equilibrium Computations of the Marginal Welfare Costs of Taxes in the United States," *The American Economic Review* 75(1): 128–138.
Bandara, Jayatilleke S. (1991). "Computable General Equilibrium Models for Development Policy Analysis in LDCs," *Journal of Economic Surveys* 5(1): 3–69.
Beckman, Jayson, Shawn Arita, Lorraine Mitchell, and Mary E. Burfisher (2015). *Agriculture in the Transatlantic Trade and Investment Partnership: Tariffs,*

Tariff-rate Quotas, and Non-tariff Measures. Research Report Number 198, Economic Research Service, U.S. Department of Agriculture.

Benjamin, Nancy, Shantayanan, and Robert J. Weiner (1989). "The 'Dutch' Disease in a Developing Country: Oil Reserves in Cameroon," *Journal of Development Economics* 30(1): 71–92.

Bergman, Lars (1988). "Energy Policy Modeling: A Survey of General Equilibrium Approaches," *Journal of Policy Modeling* 10(3): 377–399.

Bergman, Lars (2005). "CGE Modeling of Environmental Policy and Resource Management," in Karl-Göran Mäler and Jeffrey R. Vincent, eds., *Handbook of Environmental Economics*. Volume 3. Amsterdam: Elsevier, North Holland.

Berrittella, Maria, Andrea Bigano, Roberto Roson, and Richard S. J. Tol (2004). "A General Equilibrium Analysis of Climate Change Impacts on Tourism." Working Paper FNU-49, Research Unit on Sustainability and Global Change. Hamburg: Hamburg University.

Bhattacharyya, Subhes C. (1996). "Applied General Equilibrium Models for Energy Studies: A Survey," *Energy Economics* 18: 145–164.

Block, Paul J., Kenneth Strzepek, Mark Rosegrant, and Xinshen Diao (2006). *Impacts of Considering Climate Variability on Investment Decisions in Ethiopia*. EPT Discussion Paper No. 150. Washington, DC: International Food Policy Research Institute.

Boccanfuso, Dorothee, Luc Savard, and Antonio Estache (2013). "The Distributional Impact of Developed Countries' Climate Change Policies on Senegal: A Macro-Micro CGE Application," *Sustainability* 5: 2727–2750.

Borges, Antonio M. (1986). *Applied General Equilibrium Models: An Assessment of Their Usefulness for Policy Analysis*. OECD Economic Studies no. 7. Accessed June 12, 2010 from www.oecd.org/dataoecd/52/32/35567467.pdf.

Borjas, George (2004). *Increasing the Supply of Labor Through Immigration: Measuring the Impact on Native-Born Workers*. Washington, DC: Center for Immigration Studies.

Bouet, Antoine (2008). *The Expected Benefits of Trade Liberalization for World Income and Development: Opening the "Black Box" of Global Trade Modeling*. Food Policy Review No. 8. Washington, DC: International Food Policy Research Institute.

Bourguignon, Francois, Anne-Sophie Robilliard, and Sherman Robinson. (2003). "Representative Versus Real Households in the Macro-Economic Modeling of Inequality." DELTA Working Paper 2003–05. Departement et Laboratoire d'Economies Theorique et Applique. Paris: Ecole Normale Superieure.

Breisinger, Clemens, Marcelle Thomas, and James Thurlow (2009). *Social Accounting Matrices and Multiplier Analysis: An Introduction with Exercises*. Food Security in Practice Technical Guide 5. Washington, DC: International Food Policy Research Institute.

Brown, Drusilla K. (1987). "Tariffs, the Terms of Trade, and National Product Differentiation," *Journal of Policy Modeling* 9(3): 503–526.

Browning, Edgar (1976). "The Marginal Cost of Public Funds," *The Journal of Political Economy* 84(2): 283–298.

Bruinsma, Jelle (2011). "The Resources Outlook: By How Much do Land, Water and Crop Yields Need to Increase by 2050?" in Piero Conforti, ed., *Looking Ahead in World Food and Agriculture: Perspectives to 2050*. Rome, Italy: Food and Agriculture Organization.

Bulman, Timothy, et al. (2014). *The Economic Impact of the 2014 Ebola Epidemic: Short and Medium Term Estimates for West Africa*. Washington, DC: World Bank. Accessed July 16, 2016 from www.openknowledge.worldbank.org/bitstream/handle/10986/20396/912190WP0see0a00070385314B00PUBLIC0.pdf?sequence=1

Burfisher, Mary E., John Dyck, Birgit Meade, Lorraine Mitchell, John Wainio, Steven Zahniser, Shawn Arita, and Jayson Beckman (2014). *Agriculture in the Trans-Pacific Partnership*. Economic Research Report No. 175, Economic Research Service. Washington, DC: U.S. Department of Agriculture.

Burfisher, Mary E., Sherman Robinson, and Karen Thierfelder (1994). "Wage Changes in a U.S.-Mexico Free Trade Area: Migration versus Stolper-Samuelson Effects," in Joseph F. Francois and Clint R. Shiells, eds., *Modelling Trade Policy: Applied General Equilibrium Assessments of North American Free Trade*. Cambridge: Cambridge University Press.

Burniaux, Jean-Marc and Truong Truong (2002). *GTAP-E: An Energy-Environmental Version of the GTAP Model*. GTAP Technical Papers 923, Center for Global Trade Analysis. West Lafayette, IN: Purdue University.

Cadot, Olivier and Julien Gourdon (2015). "NTMs, Preferential Trade Agreements, and Prices: New Evidence." Working Paper No. 2015-01. Paris: Centre d'Etudes Prospectives et d'Informations Internationales.

Cattaneo, Andrea, Raúl A. Hinojosa-Ojeda, and Sherman Robinson (1999). "Costa Rica Trade Liberalization, Fiscal Imbalances, and Macroeconomic Policy: a Computable General Equilibrium Model," *The North American Journal of Economics and Finance* 10(1): 39–67.

Chisari, Omar O., Gustavo Ferro, and Javier A. Maquieyra (2014). "Could Corporate Governance Practices Enhance Social Welfare?" *International Journal of Disclosure and Governance* 11: 99–113.

Christen, Elisabeth, Joseph Francois, and Bernard Hoekman (2013). "CGE Modeling of Market Access in Services," in Peter B. Dixon and Dale W. Jorgenson, eds., *Handbook of Computable General Equilibrium Modeling*, Vol. 1. Oxford: Elsevier.

Cline, William (2007). *Global Warming and Agriculture: Impact Estimates by Country*. Washington, DC: Center for Global Development.

Collier, Paul (2008). "The Politics of Hunger: How Illusion and Greed Fan the Food Crisis," *Foreign Affairs* 87(6): 67–79.

Condon, Timothy, Henrik Dahl, and Shantayanan Devarajan (1987). *Implementing a Computable General Equilibrium Model in GAMS: the Cameroon Model*. DRD Discussion paper No. DRD290. Washington, DC: World Bank.

Corden, W. Max and J. Peter Neary (1982). "Booming Sector and De-industrialisation in a Small Open Economy," *The Economic Journal* 92(368): 825–848.

Dean, Judith M. (1992), "Trade and the Environment: A Survey of the Literature," in Patrick Low, ed., *International Trade and the Environment*, World Bank Discussion Papers No. 159. Washington, DC: World Bank.

Deardorff, Alan V. and Robert M. Stern (1997), "Measurement of Non-Tariff Barriers." OECD Economics Department Working Papers No. 179 (OCDE/GD(97)/129). Paris: Organization for Economic Cooperation and Development. Accessed June 14, 2014 from www.oecd-ilibrary.org/economics/measurement-of-non-tariff-barriers_568705648470?crawler=true.

Decaluwe, Bernard and Andre Martens (1988). "CGE Modeling and Developing Economies – A Concise Empirical Survey of 73 Applications to 26 Countries," *Journal of Policy Modeling* 10(4): 529–568.

deMelo, Jaime (1988). "Computable General Equilibrium Models for Trade Policy Analysis in Developing Countries: A Survey," *Journal of Policy Modeling* 10(3): 469–503.

deMelo, Jaime and David G. Tarr (1992). *A General Equilibrium Analysis of U.S. Foreign Trade Policy*. Cambridge, MA: MIT Press.

Dervis, Kemal, Jaime de Melo, and Sherman Robinson (1982). *General Equilibrium Models for Development Policy*. Cambridge: Cambridge University Press.

Devarajan, Shantayanan and Delfin S. Go (1998). "The Simplest Dynamic General Equilibrium Model of an Open Economy," *Journal of Policy Modeling* 20(6): 677–714.

Devarajan, Shantayanan, Delfin S. Go, Jeffrey D. Lewis, Sherman Robinson, and Pekka Sinko (1997). "Simple General Equilibrium Modeling," in Joseph F. Francois and Kenneth A. Reinert, eds., *Applied Methods for Trade Policy Analysis: A Handbook*. Cambridge: Cambridge University Press.

Devarajan, Shantayanan, Jeffrey Lewis, and Sherman Robinson (1990). "Policy Lessons from Trade-Focused, Two-Sector Models," *Journal of Policy Modeling* 12(4): 625–657.

Devarajan, Shantayanan, Karen E. Thierfelder, and Sethaput Suthiwart-Narueput (2001). "The Marginal Cost of Public Funds in Developing Countries," in Amedeo Fossati and Wolfgang Wiegard, eds., *Policy Evaluations with Computable General Equilibrium Models*. New York: Routledge Press.

Dewatripont, Mathias and Gilles Michel (1987). "On Closure Rules, Homogeneity and Dynamics in Applied General Equilibrium Models," *Journal of Development Economics* 26(1): 65–76.

Diao, Xinshen (2009). *Economywide Impact of Avian Flu in Ghana: A Dynamic CGE Model Analysis*. IFPRI Discussion Paper 00866. Washington, DC: International Food Policy Research Institute.

Diao, Xinshen, Rachid Doukkali, and Bingxin Yu (2008). *Policy Options and Their Potential Effects on Moroccan Small Farmers and the Poor Facing Increased World Food Prices: A General Equilibrium Model Analysis*. Development Strategy and Government Division. IFPRI Discussion Paper 00813. Washington, DC: International Food Policy Research Institute.

Diao, Xinshen, Agapi Somaru, and Terry Roe (2001). "A Global Analysis of Agricultural Reform in WTO Member Countries," in Mary E. Burfisher, ed., *Agricultural Policy Reform: The Road Ahead*. Agricultural Economics Report No. 802. Economic Research Service. Washington, DC: U.S. Department of Agriculture.

Dixon, Peter B. and Dale W. Jorgenson, eds. (2013). *Handbook of Computable General Equilibrium Modeling*, Volumes 1 and 2. Amsterdam: B. Elsevier, BV.

Dixon, Peter B. and Maureen Rimmer (2002). *Dynamic, General Equilibrium Modelling for Forecasting and Policy: a Practical Guide and Documentation of MONASH*. Amsterdam: North Holland.

Dixon, Peter B., Maureen Rimmer, and Marinos Tsigas (2007). "Regionalizing Results from a Detailed CGE Model: Macro, Industry and State Effects in the United States of Removing Major Tariffs and Quotas," *Papers in Regional Science* 86(1): 31–55.

ECORYS Nederland BV (2009). *Non-tariff Measures in EU-US Trade and Investment – An Economic Analysis*. ECORYS, Rotterdam, Netherlands. Accessed September 3, 2014 from http://trade.ec.europa.eu/doclib/docs/2009/december/tradoc_145613.pdf.

Elliott, Joshua, Ian Foster, Kenneth Judd, Elisabeth Moyer, and Todd Munson (2010a). *CIM-EARTH: Community Integrated Model of Economic and Resource Trajectories for Humankind*, Version 0.1. Mathematics and Computer Science Division, Technical Memorandum ANL/MCS-TM-307, Argonne National Laboratories, Argonne, IL.

Elliott, Joshua, Ian Foster, Samuel Kortum, Todd Munson, Fernando Perez Cervantes, and David Weisbach (2010b). "Trade and Carbon Taxes," *American Economic Review* 100(2): 465–469.

Erkel-Rousse, Helene and Daniel Mirza (2002). "Import Price Elasticities: Reconsidering the Evidence," *Canadian Journal of Economics* 35(2): 282–306.

Evans, David K., Francisco Ferreira, Hans Lofgren, Maryla Maliszewska, Mead Over, and Marcio Cruz (2014). *Estimating the Economic Impact of the Ebola Epidemic: Evidence from Computable General Equilibrium Models*. Accessed November 1, 2015 from www.gtap.agecon.purdue.edu/resources/download/7591.pdf.

Ferrantino, Michael. (2006), "Quantifying the Trade and Economic Effects of Non-Tariff Measures," *OECD Trade Policy Papers*, No. 28. Paris: OECD Publishing. Accessed January 5, 2015 from www.oecd-ilibrary.org/docserver/download/5l9z8wbgns41.pdf?expires=1422388059&id=id&accname=guest&checksum=DCFDFF6B965C92BF93B1CE46FB57D587.

Fouré, Jean, Agnès Bénassy-Quéré, and Lionel Fontagné (2012). "The Great Shift: Macroeconomic Projections for the World Economy at the 2050 Horizon." Working Paper No. 2012–03. Paris: Centre d'Etudes Prospectives et d'Informations Internationales.

Fox, Alan, Francois, Joseph, and Pilar Londono-Kent (2003). "Measuring Border Crossing Costs and their Impact on Trade Flows: The United States-Mexico Trucking Case." Paper presented at the 6th Annual GTAP Conference. Accessed January 12, 2015 from www.gtap.agecon.purdue.edu/access_staff/resources/res_display.asp?RecordID=1282.

Francois, Joseph F., Miriam Manchin, Hanna Norberg, Olga Pindyuk, and Patrick Tomberger (2013). *Reducing Transatlantic Barriers to Trade and Investment: An Economic Assessment*. London: Center for Economic Policy Research. Accessed January 27, 2015 from http://trade.ec.europa.eu/doclib/docs/2013/march/tradoc_150737.pdf.

Francois, Joseph F. and Kenneth A. Reinert (1997). "Applied Methods for Trade Policy Analysis: An Overview," in Joseph F. Francois and Kenneth A. Reinert, eds., *Applied Methods for Trade Policy Analysis: A Handbook*. Cambridge: Cambridge University Press.

Fugazza, Marco and Jean-Christophe Maur (2008). *Non-Tariff Barriers in Computable General Equilibrium Modelling*. Policy Issues in International Trade and Commodities Study Series No. 38. New York and Geneva: United Nations Conference on Trade and Development, United Nations. Accessed February 12, 2015 from http://unctad.org/en/docs/itcdtab39_en.pdf.

Gallaway, Michael P., Christine A. McDaniel, and Sandra A. Rivera (2000). "Short-Run and Long-Run Industry-Level Estimates of U.S. Armington Elasticities," *The North American Journal of Economics and Finance* 14(1): 49–68.

Gehlhar, Mark (1997). "Historical Analysis of Growth and Trade Patterns in the Pacific Rim: An Evaluation of the GTAP Framework," in Thomas W. Hertel, ed., *Global Trade Analysis: Modeling and Applications*. Cambridge: Cambridge University Press.

Giesecke, James A. and John R. Madden (2013). "Regional Computable General Equilibrium Modeling," in Peter B. Dixon and Dale W. Jorgenson, eds., *Handbook of Computable General Equilibrium Modeling*, Vol. 1A. Oxford: Elsevier.

Goel, Rajeev K. and Michael A. Nelson (2004). "International Patterns of Cigarette Smoking and Global Antismoking Policies," *Journal of Economics and Finance* 28(3): 382–394.

Gottschalk, Jan, Vu Manh Le, Hans Lofgren, and Kofi Nouve (2009). "Analyzing Fiscal Space Using MAMs: An Application to Burkina Faso." IMF Working Paper WP/09/277. Washington, DC: International.

Goulder, Lawrence H. and Barry Eichengreen (1989). "Trade Liberalization in General Equilibrium: Intertemporal and Interindustry Effects." National Bureau of Economics Working Paper No. 2965. Cambridge, MA: National Bureau of Economics.

Goulder, Lawrence H., Ian W. H. Parry, Roberton C. Williams III, and Dallas Burtraw (1998). *The Cost-Effectiveness of Alternative Instruments for Environmental Protection in a Second-Best Setting*. Discussion Paper 98–22. Washington, DC: Resources for the Future.

Guimbard, Houssein, Sebastien Jean, and Mondher Mimouni (2012). *MAcMAP-HS6 2007, an Exhaustive and Consistent Measure of Applied Protection in 2007*. Accessed August 1, 2016 from www.gtap.agecon.purdue.edu/resources/download/5668.pdf.

Hanoch, Giora (1975). "Production and Demand Models with Direct or Indirect Implicit Additivity," *Econometrica* 43(3): 395–419.

Harberger, Arnold C. (1964). "Taxation, Resource Allocation, and Welfare," in *The Role of Direct and Indirect Taxes in the Federal Reserve System*. Cambridge, MA: National Bureau of Economic Research. Accessed November 6, 2009 from www.nber.org/books/unkn.

Harrison, W. Jill, K. R. Pearson, Alan A. Powell, and E. John Small (1993). "Solving Applied General Equilibrium Models Represented as a Mixture of Linearized and Levels Equations." COPS-Impact Working Paper No. IP-61. Centre of Policy Studies, Victoria University, Melbourne.

Hertel, Thomas W., J. Mark Horridge, and Kenneth Pearson (1991a). "Mending the Family Tree: A Reconciliation of the Linearization and Levels Schools of CGE Modeling." Preliminary Working Paper No. IP-54. IMPACT Project, University of Melbourne, Australia.

Hertel, Thomas W., David L. Hummels, Maros Ivanic, and Roman Keeney (2004a). "How Confident Can We Be in CGE-Based Assessments of Free Trade Agreements?" NBER Working Paper No. W10477. Cambridge, MA: National Bureau of Economic Research.

Hertel, Thomas W., Maros Ivanic, Paul V. Preckel, and John A. L. Cranfield (2004b). "The Earnings Effects of Multilateral Trade Liberalization: Implications for Poverty," *The World Bank Economic Review* 18(2): 205–236.

Hertel, Thomas W., Everett B. Peterson, Paul V. Preckel, Yves Surry, and Marinos E. Tsigas (1991b). "Implicit Additivity as a Strategy for Restricting the Parameter Space in CGE Models," *Economic and Financial Computing* 1(1): 265–289.

Hertel, Thomas W. and Marinos E. Tsigas (1997). "Structure of GTAP," in Thomas W. Hertel, ed., *Global Trade Analysis: Modeling and Applications*. Cambridge: Cambridge University Press.

Hertel, Thomas W., Teri Walmsley, and Ken Itakura (2001). "Dynamic Effects of the "New Age" Free Trade Agreement between Japan and Singapore," *Journal of Economic Integration*, 16(4): 446–484.

Hillberry, Russell and David Hummels (2013). "Trade Elasticity Parameters for a Computable General Equilibrium Model," in Peter B. Dixon and Dale W. Jorgenson, eds., *Handbook of Computable General Equilibrium Modeling*, Vol. 1B. Oxford: Elsevier.

Horridge, Mark (2001). *Run GTAP – Demo Version*. GTAP Resource No. 411. Center for Global Trade Analysis. West Lafayette, IN: Purdue University.

Horridge, Mark (2015a). "GTAPAgg: Data Aggregation Program," in Badri G. Narayanan, Angel Aguiar, and Robert McDougall, eds., *Global Trade, Assistance, and Production: The GTAP 9 Data Base*. Center for Global Trade Analysis. West Lafayette, IN: Purdue University.

Horridge, Mark (2015b). *GTAPAgg Demo Version*. GTAP Resource No. 807. Center for Global Trade Analysis. West Lafayette, IN: Purdue University. Accessed May 23, 2015 from www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=807.

Horridge, Mark, Alex Meeraus, Ken Pearson, and Thomas F. Rutherford (2013). "Solution Software for Computable General Equilibrium Modeling," in Peter B. Dixon and Dale W. Jorgenson, eds., *Handbook of Computable General Equilibrium Modeling*, Vol. 1A. Oxford: Elsevier.

Horridge, Mark and Ken Pearson (2011). *Solution Software for CGE Models*. General Paper No. G-214. Centre of Policy Studies and the Impact Project. Clayton, Australia: Monash University.

Hosoe Nobuhiro, Kenji Gasawa, and Hideo Hashimoto (2010). *Textbook of Computable General Equilibrium Modelling: Programming and Simulations*. Houndsmills, UK: Palgrave Macmillan.

Huff, Karen M. and Thomas W. Hertel (2000). *Decomposing Welfare Changes in the GTAP Model*. GTAP Technical Paper No. 5. Center for Global Trade Analysis. West Lafayette, IN: Purdue University.

Hummels, David (1999). "Towards a Geography of Trade Costs." GTAP Working Paper No. 17. West Lafayette, IN: Center for Global Trade Analysis, Purdue University.

Hummels, David (2007). "Transportation Costs and International Trade in the Second Era of Globalization," *The Journal of Economic Perspectives* 21(3): 131–154.

International Labor Organization (2015). LABORSTA Internet. Accessed October 28, 2015 from www.laborsta.ilo.org.

IPCC (2013). "Summary for Policymakers," in T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley, eds., *Climate Change 2013: The Physical Science Basis*. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.

Jabara, Cathy, Mary E. Burfisher, and David Ingersoll (2008). "Wood Packaging SPS Regulations: Effects on U.S. Imports and Containerized Trade." U.S. International Trade Commission, Office of Industries Working Paper No. 20. Washington, DC: U.S. International Trade Commission.

Johnson, Harry G. (1962). "The Economic Theory of Customs Union," in *Money, Trade and Economic Growth: Survey Lectures in Economic Theory*. New York: Routledge.

Jokisch, Sabine and Laurence J. Kotlikoff (2005). "Simulating the Dynamic Macroeconomic and Microeconomic Effects of the FairTax." NBER Working Paper No. 11858. Cambridge, MA: National Bureau of Economic Research.

Kehoe, Patrick J. and Timothy J. Kehoe (1994). "A Primer on Static Applied General Equilibrium Models," *Federal Reserve Bank of Minneapolis Quarterly Review*, 18(1). Accessed December 4, 2015 from http://minneapolisfed.org/research/qr/qr1821.pdf.

Keller, Wouter J. (1980). *Tax Incidence: A General Equilibrium Approach*. Amsterdam: North Holland.

Kendall, Lindsay and James Gaisford (2007). "Trade Creation and Trade Diversion: Analyzing the Impact of Regional Trade Agreements," in William A. Kerr and James Gaisford, eds., *Handbook on International Trade Policy*. Glos, UK: Edward Elgar Publishers.

Keogh, Marcus, Scott McDonald, Richard Smith, Melisa Martinez-Alvarez, and Jo Coast (2009). *Global CGE Modeling of Antibiotic Resistance: An Application of the GLOBE Model*. GTAP Resource No. 3093. Center for Global Trade Analysis. West Lafayette, IN: Purdue University.

King, Benjamin B. (1985). "What Is a SAM?" in Graham Pyatt and Jeffrey I. Round, eds., *Social Accounting Matrices: A Basis for Planning*. Washington, DC: The World Bank.

Koesler, Simon and Michael Schymura (2012). *Substitution Elasticities in a CES Production Framework – An Empirical Analysis on the Basis of Non-Linear Least Squares Estimations*. ZEW – Centre for European Economic Research Discussion Paper No. 12-007. Mannheim, Germany.

Koopman, Robert, Hugh Arce, Edward J. Balistreri, and Alan Fox (2002). *Large Scale CGE Modeling at the United States International Trade Commission*. GTAP Resource No. 1051. Center for Global Trade Analysis. West Lafayette, IN: Purdue University.

Kuiper, Marijke and Frank van Tongeren (2006). *Using Gravity to Move Armington*. GTAP Resource No. 2044. Center for Global Trade Analysis. West Lafayette, IN: Purdue University.

Landes, Maurice and Mary E. Burfisher (2009). *Food and Agricultural Marketing Efficiency Gains in India: A Source of Growth and Equity*. Economic Research Report No. ERR-89. Economic Research Service. Washington, DC: U.S. Department of Agriculture.

Latorre, María C. (2016). "A CGE Analysis of the Impact of Foreign Direct Investment and Tariff Reform on Female and Male Workers in Tanzania," *World Development* 77: 346–366.

Lipsey, Richard G. and Kelvin J. Lancaster (1956). "The General Theory of Second Best," *Review of Economic Studies* 24(12): 11–32.

Löfgren, Hans, Rebecca Lee Harris, and Sherman Robinson (2002). *A Standard Computable General Equilibrium (CGE) Model in GAMS*. Microcomputers in Policy Research, No. 5. Washington, DC: International Food Policy Research Institute.

Malcolm, Gerard (1998). *Adjusting Tax Rates in the GTAP Data Base*. GTAP Technical Papers, No. 12. Center for Global Trade Analysis. West Lafayette, IN: Purdue University.

McDaniel, Christine A. and Edward J. Balistreri (2003). "A Discussion on Armington Trade Substitution Elasticities." USITC Office of Economics Working Paper No. 2002-01-A. Washington, DC: U.S. International Trade Commission.

McDaniel, Christine A., Kenneth Reinert, and Kent Hughes (2008). *Tools of the Trade: Models for Trade Policy Analysis*. Washington, DC: Woodrow Wilson International Center for Scholars.

McDonald, Scott, Karen Thierfelder and Sherman Robinson (2007). "GLOBE: A SAM Based Global CGE Model Using GTAP Data." USNA Economics Department Working Paper No. 15. Annapolis, MD: United States Naval Academy.

McDougall, Robert (2003). *A New Regional Household Demand System for GTAP*. GTAP Technical Paper No. 20, Revision 1. Center for Global Trade Analysis. West Lafayette, IN: Purdue University.

McDougall, Robert (2009). *Elasticities of Substitution in Nested CES Systems*. GTAP Research Memorandum No. 16. Center for Global Trade Analysis. West Lafayette, IN: Purdue University.

McDougall, Robert, Zeynep Akgul, Terrie Walmsley, Tom Hertel, and Nelson Villoria (2012). "General Equilibrium Mechanisms and the Real Exchange Rate in the GTAP Model, Third Draft of a Technical Document." Accessed December 14, 2015 from www.gtap.agecon.purdue.edu/AgEc618/modules/Macro_Decomposition/GE_Mechanisms.pdf.

Melitz, Marc J. (2003). "The Impact of Trade on Intra-Industry Reallocations and Aggregate Industry Productivity," *Econometrica* 71(6): 1695–1725.

Narayanan, Badri and Thomas W. Hertel (2015). "Chapter 1: Introduction," in G. Narayanan, Angel Aguiar Badri, and Robert McDougall, eds., *Global Trade,* *Assistance, and Production: The GTAP 9 Data Base*. West Lafayette, IN: Center for Global Trade Analysis, Purdue University.

Nelson, G. C, H. Valin, R. D. Sands, P. Havlík, H. Ahammad, D. et al. (2014). "Climate Change Effects on Agriculture: Economic Responses to Biophysical Shocks," *Proceedings of the National Academy of Sciences (PNAS)* 111 (9): 3274–3279.

Nielson, Chantal Pohl, Karen Thierfelder, and Sherman Robinson (2001). *Genetically Modified Foods, Trade and Developing Countries*. TMD Discussion Paper No. 77. Washington, DC: International Food Policy Research Institute.

Ottaviano, Gianmarco I. P. and Giovanni Peri (2012). "Rethinking the Effect of Immigration on Wages: New Data and Analysis from 1980–2004," *Journal of the European Economic Association* 10(1): 152–197.

Paltsev, Sergey, John M. Reilly, Henry D. Jacoby, Richard S. Eckaus, James McFarland, et al. (2005). *The MIT Emissions Prediction and Policy Analysis (EPPA) Model: Version 4*. Report No. 125. Joint Program Report Series. Cambridge, MA: Massachusetts Institute of Technology.

Paltsev, Sergey John M. Reilly, Henry D. Jacoby, Angelo C. Gurgel, Gilbert E. Metcalf, et al. (2007). *Assessment of U.S. Cap-and-Trade Proposals*. Report No. 146. Joint Program Report Series. Cambridge, MA: Massachusetts Institute of Technology.

Paltsev, Sergey, John M. Reilly, Henry D. Jacoby, and Kok Hoh Tay (2004). *The Cost of Kyoto Protocol Targets: The Case of Japan*. Report No. 112. Joint Program Report Series. Cambridge, MA: Massachusetts Institute of Technology.

Panagariya, Arvind (2000). "Preferential Trade Liberalization: The Traditional Theory and New Developments," *Journal of Economic Literature* 38: 288–331.

Partridge, Mark D. and Dan S. Rickman (1998). "Regional Computable General Equilibrium Modeling: A Survey and Critical Appraisal," *International Regional Science Review* 21(3): 205–248.

Pearson, Kenneth and Mark Horridge (2003). *Hands-on Computing with RunGTAP and WinGEM to Introduce GTAP and GEMPACK*. Resource Paper No. 1638. Center for Global Trade Analysis. West Lafayette, IN: Purdue University.

Pereira, Alfredo M. and John B. Shoven (1988). "Survey of Dynamic Computable General Equilibrium Models for Tax Policy Evaluation," *Journal of Policy Modeling* 10(3): 401–436.

Petri, Peter and Michael G. Plummer (2012). *The Trans-Pacific Partnership and Asia-Pacific Integration: Policy Implications*. Policy Brief No. PB12–16. Washington, DC: Peterson Institute for International Economics.

Piermartini, Roberta and Robert Teh (2005). *Demystifying Modelling Methods for Trade Policy*. Discussion Paper No. 10. Geneva: World Trade Organization.

Pineiro, Valeria, Jenny Thomas and Pablo Elverdin (2016). *The Agricultural Sector as an Alternative to Illegal Mining in Peru: Madre de Dios as a Case Study*. IFPRI Discussion Paper, International Food Policy Research Institute, Washington, DC.

Powell, Alan A. and F. H. G. Gruen (1968). "The Constant Elasticity of Transformation Production Frontier and Linear Supply System," *International Economic Review* 9(3): 315–328.

Pyatt, Graham and Jeffrey I. Round (1985). "Social Accounting Matrices for Development Planning," in Graham Pyatt and Jeffrey I. Round, eds., *Social Accounting Matrices: A Basis for Planning*. Washington, DC: World Bank.

Reinert, Kenneth A. and David W. Roland-Holst (1992). "Armington Elasticities for United States Manufacturing Sectors," *Journal of Policy Modeling* 14(5): 631–639.

Reinert, Kenneth A. and David W. Roland-Holst (1997). "Social Accounting Matrices," in Joseph F. Francois and Kenneth A. Reinert, eds., *Applied Methods for Trade Policy Analysis: A Handbook*. Cambridge: Cambridge University Press.

Robinson, Sherman (1991). "Macroeconomics, Financial Variables, and Computable General Equilibrium Models," *World Development* 19(11): 1509–1525.

Robinson, Sherman (2006). "Macro Models and Multipliers: Leontief, Stone, Keynes, and CGE Models," in Alain de Janvry and Ravi Kanbur, eds., *Poverty, Inequality and Development: Essays in Honor of Erik Thorbecke*. New York: Springer Science.

Robinson, Sherman, Maureen Kilkenny, and Kenneth Hanson (1990). *The USDA/ERS Computable General Equilibrium Model of the United States*. Agriculture and Rural Economy Division Report No. AGES 9049. Economic Research Service. Washington, DC: U.S. Department of Agriculture.

Robinson, Sherman and Karen Thierfelder (2002). "Trade Liberalization and Regional Integration: The Search for Large Numbers," *Australian Journal of Agricultural and Resource Economics* 46(6): 585–604.

Robinson, Sherman, Antonio Yunez-Naude, Raul Hinojosa-Ojeda, Jeffrey D. Lewis, and Shantayanan Devarajan (1999). "From Stylized to Applied Models: Building Multi-sector CGE models for Policy Analysis," *North American Journal of Economics and Finance* 10(1999): 5–38.

Rutherford, Thomas F. and David G. Tarr (2003). "Regional Trading Arrangements for Chile: Do the Results Differ with a Dynamic Model?" *Économie internationale* 94–95: 261–281.

Rybczynski, Tadeusz M. (1955). "Factor Endowments and Relative Commodity Prices," *Economica*, New Series, 22(88): 336–341.

Sachs, Jeffrey D. (2008). "Surging Food Prices Mean Global Instability," *Scientific American*, June. Accessed January 3, 2009 from: www.scientificamerican.com/article.cfm?id=surging-food-prices.

Sakamoto, Hiroshi (2012). "CGE Analysis of Transportation Cost and Regional Economy: East Asia and Northern Kyushu," *Regional Science Inquiry Journal* 4(1): 121–140.

Samuelson, Paul A. (1954). "The Transfer Problem and Transport Costs, II: Analysis of the Effects of Trade Impediments," *Economic Journal* 64: 264–289.

Samuelson, Robert (2005). "The Endless Food Fight," *Washington Post*, December 4, p. A29.

Scarf, Herbert E. and John B. Shoven (2008). *Applied General Equilibrium Analysis*. Cambridge: Cambridge University Press.

Shiells, Clinton R. and Kenneth A. Reinert (1993). "Armington Models and Terms-of-Trade Effects: Some Econometric Evidence for North America," *Canadian Journal of Economics* 26(2): 299–316.

Shiells, Clinton R., Robert M. Stern, and Alan V. Deardorff (1986). "Estimates of the Elasticities of Substitution between Imports and Home Goods for the United States," *Weltwirtschaftliches-Archiv* 122(3): 497–519.

Shoven, John B., and John Whalley (1984). "Applied General-Equilibrium Models of Taxation and International Trade: An Introduction Survey," *Journal of Economic Literature* 22(3): 1007–1051.

Shoven, John B. and John Whalley (1992). *Applying General Equilibrium*. Cambridge: Cambridge University Press.

Siddig, Khalid and Harald Grethe (2014). "International Price Transmission in CGE Models: How to Reconcile Econometric Evidence and Endogenous Model Response?" *Economic Modeling* 38: 12–22.

SSP Database, v. 0.9.3 (2012). Accessed September 4, 2014 from https://secure.iiasa.ac.at/web-apps/ene/SspDb/dsd?Action=htmlpage&page=about.

Sullivan, Evan (2010). "A CGE-based Analysis of the Effects of Piracy in Somalia on Global Markets in Grains and Petroleum." Unpublished research memo, Department of Economics. Annapolis, MD: United States Naval Academy.

Surry, Yves (1993). "The 'Constant Difference of Elasticities' Function with Applications to the EC Animal Feed Sector," *Journal of Agricultural Economics* 44(1): 110–125.

Tarr, David G. (2013). "Putting Services and Foreign Direct Investment with Endogenous Productivity Effects in Computable General Equilibrium Models," in Peter B. Dixon and Dale W. Jorgenson, eds., *Handbook of Computable General Equilibrium Modeling*, Vol. 1A Amsterdam: B. Elsevier, BV.

Taylor, J. Edward, Antonio Yunez-Naude, and Steve Hampton (1999). "Agricultural Policy Reform and Village Economics: A CGE Analysis from Mexico," *Journal of Policy Modeling* 21(4): 453–480.

Thierfelder, Karen E. (2009). "Tools for Undergraduates (TUG) CGE Model." Accessed October 1, 2009 from www.usna.edu/users/econ/thier.

Thierfelder, Karen and Scott McDonald (2011). "Globe v1: A SAM Based Global CGE Model using GTAP Data." Department of Economics Working Paper No. 2011-39. Annapolis, MD: U.S. Naval Academy.

Trostle, Ronald (2008). *Global Agricultural Supply and Demand: Factors Contributing to the Recent Increase in Food Commodity Prices*. Economic Research Service WRS-0801 (revised July 2008). Washington, DC: United States Department of Agriculture.

United Nations Conference on Trade and Development (UNCTAD) (2015). International Classification of Nontariff Measures. UNCTAD/DITC/TAB/2012/2/Rev.1. Geneva: United Nations.

United Nations Development Program (UNDP) (2016). *Climate Change and Labour: Impacts of Heat in the Workplace*. UNDP, New York. Accessed August 16, 2016 from www.ilo.org/wcmsp5/groups/public/–ed_emp/–gjp/documents/publication/wcms_476194.pdf.

United States Bureau of Labor Statistics (2015). *Employment Projections*. Accessed October 28, 2015 from www.bls.gov/emp/ep_table_301.htm.

United States Census Bureau, Department of Commerce (2015). American *Factfinder Data Profile*. Accessed December 9, 2015 from htttp://factfinder.census.gov.

United States Department of Agriculture, Economic Research Service (2015). *International Macroeconomic Data Set*. Accessed October 28, 2015 from www.ers.usda.gov/data-products/international-macroeconomic-data-set.aspx.

United States Environmental Protection Agency (EPA) (2012). *Regulatory Impact Analysis: Final Rulemaking for 2017–2025 Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards*. EPA-420-R-12-016, August.

United States Trade Representative (USTR) (2016). *Transatlantic Trade and Investment Partnershpi (T-TIP)*. Accessed August 4, 2016 from www.ustr.gov/ttip.

van der Mensbrugghe, Dominique (2005). *LINKAGE Technical Reference Document, Version 6.0*. Development Prospects Group (DECPG). Washington, DC: World Bank.

van der Mensbrugghe, Dominique (2013). “Modeling the Global Economy – Forward-Looking Scenarios for Agriculture,” in Peter B. Dixon and Dale W. Jorgenson, eds., *Handbook of Computable General Equilibrium Modeling*, Vol. 1B. Amsterdam: B. Elsevier, BV.

Verma, Monika and Thomas W. Hertel (2009). *Commodity Price Volatility and Nutrition Vulnerability*. Markets, Trade and Institutions Division Discussion Paper No. 00895. Washington, DC: International Food Policy Research Institute.

Viner, Jacob (1950). *The Customs Union Issue*. New York: Carnegie Endowment for International Peace.

Walmsley, Terri and Peter Minor (2015). “Willingness to Pay in CGE Models.” ImpactECON Working Paper No. 4. ImpactECON: Boulder, CO.

World Bank (2006). *Global Economic Prospects: Economic Implications of Remittances and Migration*. Washington, DC: World Bank.

World Bank (2015). *World Bank Development Indicators Database*. Accessed October 7, 2015 from www.databank.worldbank.org/data/reports.aspx?source=world-development-indicators.

World Trade Organzation (2012). *World Trade Report 2012 Trade and Public Policies: A Closer Look at Non-tariff Measures in the 21st Century*. Accessed August 12, 2016 from www.wto.org/english/res_e/booksp_e/anrep_e/world_trade_report12_e.pdf.

Author Index

Subject Index