Textbook of Computable General Equilibrium Modelling

Programming and Simulations

Nobuhiro Hosoe,
Kenji Gasawa and
Hideo Hashimoto

Textbook of Computable General Equilibrium Modelling

This page intentionally left blank

Textbook of Computable General Equilibrium Modelling

Programming and Simulations

Nobuhiro Hosoe

Kenji Gasawa

and

Hideo Hashimoto

palgrave
macmillan

Softcover reprint of the hardcover 1st edition 2010 978-0-230-24814-4

First published 2010 by
PALGRAVE MACMILLAN

Palgrave Macmillan in the UK is an imprint of Macmillan Publishers Limited, registered in England, company number 785998, of Houndmills, Basingstoke, Hampshire RG21 6XS.

Palgrave Macmillan in the US is a division of St Martin's Press LLC, 175 Fifth Avenue, New York, NY 10010.

Palgrave Macmillan is the global academic imprint of the above companies and has companies and representatives throughout the world.

ISBN 978-1-349-32039-4 ISBN 978-0-230-28165-3 (eBook)
DOI 10.1057/9780230281653

This book is printed on paper suitable for recycling and made from fully managed and sustained forest sources. Logging, pulping and manufacturing processes are expected to conform to the environmental regulations of the country of origin.

A catalogue record for this book is available from the British Library.

Library of Congress Cataloging-in-Publication Data

Hosoe, Nobuhiro, 1972–
Textbook of computable general equilibrium modelling : programming and simulations / Nobuhiro Hosoe, Kenji Gasawa and Hideo Hashimoto.
p. cm.
ISBN 978-1-349-32039-4
1. Equilibrium (Economics)—Mathematical models. I. Gasawa, Kenji, 1971– II. Hashimoto, Hideo, 1937– III. Title.
HB145.H677 2010
339.5—dc22
2010010811

10 9 8 7 6 5 4 3 2 1
19 18 17 16 15 14 13 12 11 10

Contents

Abbreviations

Abbreviations of general terms

AGE	applied general equilibrium
ASEAN	Association of Southeast Asian Nations
CES	constant elasticity of substitution
CET	constant elasticity of transformation
CGE	computable general equilibrium
CSV	comma-separated value
EV	equivalent variation
GAMS	General Algebraic Modeling System
GAMS IDE	GAMS Integrated Development Environment
GATT	General Agreement on Tariffs and Trade
GDP	gross domestic product
GDX	GAMS Data Exchange
GTAP	Global Trade Analysis Project
IFPRI	International Food Policy Research Institute
IO	input–output
IRTS	increasing returns to scale
MDGs	millennium development goals
MFA	Multi-Fibre Arrangement
ROW	rest of the world
SAM	social accounting matrix
TOT	terms of trade
WTO	World Trade Organization

Abbreviations in social accounting matrices and GAMS input and output files

AGR	agriculture
BRD	bread
CAP	capital
EXT	external
`EPS`	epsilon, i.e., a small value close to zero
`EQU`	equation
GOV	government
HOH	household

IDT	indirect tax
INF	infinity
INV	investment
JPN	Japan
LAB	labour
MAN	manufacturing
MLK	milk
SRV	service
TRF	tariff
USA	the United States
VAR	variable

Symbols in CGE Models

Symbols indicating indices

i, j: goods and firms (BRD, MLK),
h, k: factors (CAP, LAB),
l: households (HOH1, HOH2),
r, rr: regions (JPN, USA).

Symbols in Chapter 2

[Endogenous variables]

UU: utility,
X_i: consumption of the i-th good,
Z_j: output of the j-th firm,
$F_{h,j}$: the h-th factor used by the j-th firm,
p_i^x: demand price of the i-th good,
p_j^z: supply price of the j-th good,
p_h^f: price of the h-th factor.

[Exogenous variables and constants]

FF_h: endowments of the h-th factor for the household,
α_i: share coefficient for the i-th good consumption in the utility function,
$\beta_{h,j}$: share coefficient for the h-th factor used by the j-th firm in the production function,
b_j: scaling coefficient in the production function.

Symbols in Chapter 6

[Endogenous variables]

UU: utility,
Y_j: composite factor, produced in the first stage and used in the second stage by the j-th firm,
$F_{h,j}$: the h-th factor used by the j-th firm in the first stage,
$X_{i,j}$: intermediate input of the i-th good used by the j-th firm,
Z_j: gross domestic output of the j-th firm,
X_i^p: household consumption of the i-th good,

X_i^g: government consumption of the i-th good,
X_i^v: demand for the i-th investment good,
E_i: exports of the i-th good,
M_i: imports of the i-th good,
Q_i: the i-th Armington composite good,
D_i: the i-th domestic good,
p_j^y: price of the j-th composite factor,
p_h^f: price of the h-th factor,
p_j^z: price of the j-th gross domestic output,
p_i^e: price of the i-th exported good,
p_i^m: price of the i-th imported good,
p_i^q: price of the i-th composite good,
p_i^d: price of the i-th domestic good,
ε: foreign exchange rate (domestic currency/foreign currency),
S^p: household savings,
S^g: government savings,
T^d: direct tax,
T_j^z: production tax on the j-th good,
T_i^m: import tariff on the i-th good.

[Exogenous variables and constants]

FF_h: endowments of the h-th factor for the household,
p_i^{We}: price of the i-th exported good in terms of foreign currency,
p_i^{Wm}: price of the i-th imported good in terms of foreign currency,
S^f: current account deficits in foreign currency terms (or equivalently foreign savings),
τ^d: direct tax rate,
τ_j^z: production tax rate on the j-th good,
τ_i^m: import tariff rate on the i-th good,
$ax_{i,j}$: input requirement coefficient of the i-th intermediate input for a unit output of the j-th good,
ay_j: input requirement coefficient of the j-th composite good for a unit output of the j-th good,
α_i: share coefficient for the i-th good consumption in the utility function,
$\beta_{h,j}$: share coefficient for the h-th factor used by the j-th firm in the composite factor production function,
b_j: scaling coefficient in the j-th composite factor production function,
μ_i: share of the i-th good in government expenditure,

λ_i: expenditure share of the i-th good in total investment,
ss^p: average propensity for savings by the household,
ss^g: average propensity for savings by the government,
γ_i: scaling coefficient in the i-th Armington composite good production function,
$\delta m_i, \delta d_i$: input share coefficients in the i-th Armington composite good production function,
η_i: parameter defined by the elasticity of substitution,
σ_i: elasticity of substitution in the i-th Armington composite good production function,
θ_i: scaling coefficient in the i-th good transformation function,
$\xi e_i, \xi d_i$: share coefficients in the i-th good transformation function,
ϕ_i: parameter defined by the elasticity of transformation,
ψ_i: elasticity of transformation in the i-th good transformation function.

Symbols in Chapter 10 (selective)

SW: social welfare,
RT_i: monopoly or quota rents in the i-th sector,
χ_i: quota rent rate in the i-th sector,
M_i^{quota}: quota ceiling on the i-th good imports,
FC_j: fixed production costs of the j-th firm,
ν_j: the share of the fixed cost payment to the household in total capital service payment by the j-th firm.

Tables, Figures and Lists

Tables

Figures

Computer Input/Output Lists

Preface

Computable general equilibrium (CGE) models are well grounded in standard microeconomic theory, where price is an important signal that drives agents in an economy. The modern economy cannot be examined without considering the role of the price mechanism. CGE models featuring the price mechanism are suitable for analysing contemporary policy issues in market economies and thus are used widely in various policy analyses, such as economic integration, global warming problems, tax reform, assistance for developing countries and so on. The potential of CGE models has encouraged many researchers and practitioners to cooperate in the development and use of these models; however, many of them have had difficulty in fully understanding CGE models, because of the complexity of the underlying economic theory, estimation techniques and computational requirements – this is why CGE models are sometimes called a 'black box'.

Despite the usefulness of CGE models, they have been used only infrequently in Japan. This is partly because, although many useful books and articles on CGE modelling are available in English, there were no comprehensive textbooks in Japanese, particularly for newcomers to CGE modelling. Therefore, we decided to write this textbook on CGE modelling in Japanese several years ago. Our endeavour resulted in the publication of *Textbook of Computable General Equilibrium Modeling – Programming and Simulations* by the University of Tokyo Press in 2004.

In the Japanese version of the textbook, we made considerable effort to help beginners to understand and build CGE models by themselves. The textbook was designed to be self-inclusive, proceeding in a step-by-step manner. We covered the A-to-Z of CGE modelling, starting from a basic setup of economic agents' behaviour, construction of databases, estimation of model parameters, computer programs and interpretation of simulation results. In each step, sample models with computer programs were presented.

The computer programs were written using the GAMS (General Algebraic Modeling System) software, whose trial version is publicly accessible on the GAMS web site free of charge. Assuming that most readers of this book were completely new to GAMS, we presented a detailed explanation of its use in the book. It was intended that, as readers become familiar with GAMS, they would be able to use the sample models on the GAMS web site and to become acquainted with CGE models by experimenting with these sample models.

After the publication of our textbook in Japanese, we received requests from both international students studying in Japan and researchers in other countries to publish an English version. These requests motivated us to publish this book. In this English version, we retain the features of the Japanese version outlined above. At the same time, the English version is not a mere English translation. On the one hand, considerable effort has been made to improve the clarity of the explanation and to include recent changes to GAMS and data for CGE modelling. On the other hand, we omitted several sections that were specifically written for Japanese readers; in particular, actual examples of CGE analyses.

Partly because this textbook is written for beginners, and partly because of space limitations, this textbook covers only the basic features of CGE modelling. For example, we have not discussed dynamics or the monetary economy, which are discussed in other advanced books and journal articles about CGE models. After reading through this textbook, readers can start to explore such frontiers of CGE modelling. While we are confident that this book provides readers with all the essential knowledge and techniques of CGE modelling, we would appreciate any comments and suggestions that may improve this book.

We gratefully acknowledge useful comments and suggestions by Professors Kanemi Ban and Tatsuo Hatta, and by many friends, as well as readers of the Japanese version. In the publication of the Japanese version, we acknowledged Messrs Takuya Kuroda and Toshihiro Ikeda at the University of Tokyo Press for their assistance. We thank the University of Tokyo Press for providing permission to publish this English version. Regarding the software used for the modelling discussed in this book, we are indebted to Mr Alex Meeraus and his associates in GAMS Development Corporation for their generous support of our use of GAMS in both the Japanese and English versions of our book. The use of GAMS throughout this book allows us to provide a practical introduction to CGE modelling. We gratefully acknowledge the financial support of a Grant-in-Aid for Scientific Research (No. 20330053, 21730222) by the Ministry of Education, Culture, Sports, Science and Technology of Japan and the Japan Society for the Promotion of Science. We also acknowledge MIT Press and Elsevier for granting us permission to reprint certain figures originally contained in their publications, and Microsoft Corporation and GAMS Development Corporation for granting us permission to use screen shots of their products.

1
Overview

1.1 Economic analysis with computable general equilibrium models

Efficiency of resource allocation has become increasingly important in recent years. In the 1960s and 1970s, the Japanese economy grew so rapidly that efficiency of resource allocation was a secondary issue; however, this has changed. Growth in Japan slowed from the 1980s onward to the more moderate speeds experienced in other developed economies. Most developing economies cannot expect large aid inflows and commercial financing from developed economies any more. The focus of economists has returned to an important issue in economics; namely, efficiency of scarce resource allocation.

Resource allocation can be viewed as a trade-off issue. Output can be either exported or set aside for domestic supply. Exports earn hard currency to support imports. Imports and domestic supply can be either consumed by households or used as intermediate inputs. Household consumption determines society's economic welfare, while intermediate inputs contribute to a further increase of output. As an economy has a number of agents, such as households, firms and a government, as well as various industrial sectors, it is difficult to solve these trade-off problems or to find an efficient allocation of resources among those agents and sectors under given resource and technology constraints.

The price mechanism is a powerful device capable of solving the complicated trade-off problems stated above. Economic agents, such as households and firms, make their decisions about their economic activities using price information prevailing in the markets. Many economic theories involve optimization behaviour of economic agents under given resource and technology constraints under signalling from market prices. Households maximize their utility subject to their budget constraints, and firms maximize their profits subject to their production technology constraints. Solutions of these optimization problems yield the demand and supply schedules respectively. Markets equilibrate demand and supply by adjusting prices. The prices of goods with excess supply fall, and those of goods with excess demand rise, as occurs in markets such as antique auctions and daily fish markets. This is the price mechanism. Computable general equilibrium (CGE) models can depict such market economies in a quantitative manner. Incidentally, CGE models are also sometimes called applied general equilibrium (AGE) models.

The efficiency of resource allocation is not a purely theoretical issue. Hardly a day goes by when we do not hear about 'structural reforms' in Japan. Examples of public utility reforms are deregulation of telecommunications, electric power, city gas and water supply. While the regulatory reforms are designed to improve the efficiency of resource allocation, support for the reforms among stakeholders is required. This can be done only by showing the effects of these reforms not only qualitatively but also quantitatively; that is, the economy-wide impact of the reforms and their effect on individual industrial sectors, income group, and so on. Similar arguments can be applied to so-called structural adjustment policies led by the World Bank and others in developing countries. Suppose you are an economic adviser for a developing country. Even though it is trivial to show qualitatively that import tariff reduction leads to better resource allocation, it cannot simply be recommended to the organisations responsible for the country's macroeconomic management. You have to provide concrete advice about tariff reduction in percentage terms to achieve certain policy goals such as economic welfare and GDP. At the same time, you are required to indicate its impact on various aspects of the economy numerically. The CGE models are useful for quantitative analysis and evaluation of these economic policies.

The general equilibrium theory of the competitive market economy was originated by Léon Walras. His theory was further extended to proofs of existence and stability of the equilibrium by Kenneth Arrow and Gérard Debreu.[1] These studies are of a general, abstract and rigorous nature and do not include numerical analysis. In contrast, CGE models are designed to establish a numerical framework for empirical analysis and evaluation of economic policies. This is why they are called *computable* general equilibrium models.

The pioneering CGE model was the Norwegian multisectoral growth model developed by Johansen (1960). Since then, many CGE models have been developed to analyse, for example, development issues by Dervis et al. (1982) and taxation and international trade issues by Shoven and Whalley (1992). A model of the Australian economy, known as ORANI with its variants, was built by Dixon et al. (1992). CGE modelling has become popular because of increasing needs for analysis of policies related to resource-allocation issues. At the same time, it must be noted that CGE modelling has been made possible by the algorithm introduced by Scarf (1973), in combination with rapid improvements in computer technology. Modern computers have enabled the development and solution of large-scale world trade CGE models that can analyse the impact of a series of General Agreement on Tariffs and Trade (GATT) and World Trade Organization (WTO) negotiations. The worldwide input–output (IO) tables and trade database prepared by the Global Trade Analysis Project (GTAP) at Purdue University provide the data for these analyses.[2]

1.2 Framework of CGE models

CGE models can depict numerically a 'world', where a general equilibrium is attained by the price mechanism, as stated above. A simple economy with one household and one firm is represented in Figure 1.1. In this economy, the representative household determines its consumption bundle to maximize its utility subject to its budget constraint. The firm is supposed to maximize its profits by managing its inputs and outputs subject to its production technology. This optimization behaviour yields the demand and supply curves of goods and factors of production, which are equilibrated in the markets by flexible price adjustments.

In this book, we first develop a 'simple CGE model' with two goods, two factors, one household and two firms. As it is necessary to include more detail in the model to analyse the real-world economic issues empirically, we gradually develop a more realistic model; that is, a 'standard CGE model', with a government, an external sector, investment and savings, and intermediate inputs. Once an operational knowledge of the standard CGE model is obtained, most standard economic problems can be analysed.

Both the simple CGE model and the standard CGE model primarily rely on the basic assumptions of standard microeconomics as their foundations. These models assume one representative household, which consumes goods, and two representative firms, each of which produces a certain good. The household is supposed to maximize its utility subject to its budget constraint, while the firms maximize their profits subject to given constraints on production technology. The household and all the firms are assumed to be price takers. In other words, the markets are perfectly competitive. However, in contrast to household consumption and

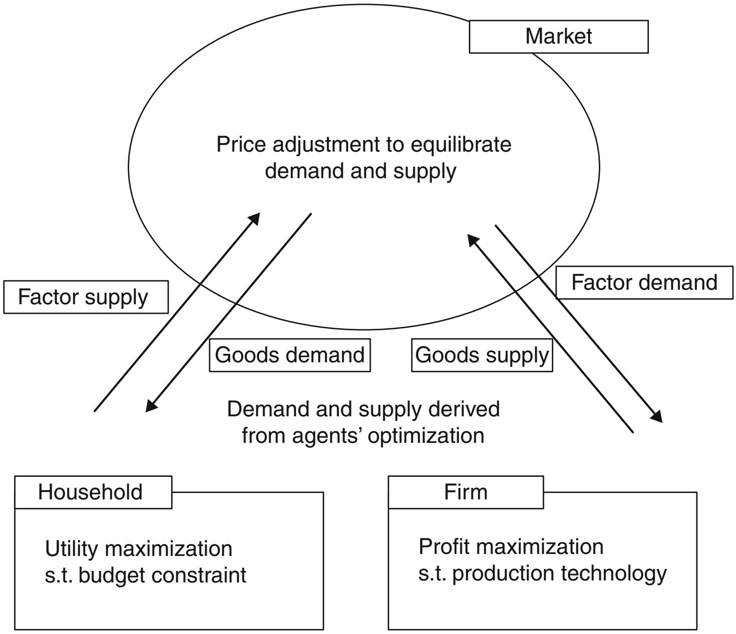

Figure 1.1 Structure of an economy

firm production, there are elements that lack microfoundations, including the behaviour of investment, savings and a government added in the standard CGE model. The problems associated with introducing investment, savings and a government into CGE models are discussed in detail, as are possible solutions.

To incorporate more complicated economic phenomena in CGE models, some of the basic assumptions stated above are replaced in the latter part of this book. First, heterogeneous households are introduced to investigate the changes in income distribution caused by certain policies or extraneous shocks. Modelling multihouseholds provides a basis for a model extension toward multiple-country models. Second, the basic assumptions regarding market structure and production technology are replaced by imperfect competition and by increasing-returns-to-scale technology. These extended CGE models are explained there.

All the CGE models dealt with in this book – simple, standard or extended – follow the Walrasian tradition. In other words, we present each of our CGE models as a system of simultaneous equations, which are derived from the agents' optimization behaviour. By Walras's law, one of the equations, against the same number of endogenous variables, is redundant; thus, (absolute) prices cannot be determined. All prices are expressed relative to a chosen numeraire.

1.3 Advantages and shortcomings of CGE models

A major advantage of CGE models is the relatively small data requirements considering the model size. This has enabled wider use of CGE analysis. As explained below in detail, most CGE models are developed with macroeconomic data, such as IO tables, national accounts tables and trade statistics, for *one year*. This advantage makes CGE models preferable to standard econometric models, which require observations for several years to estimate parameters with sufficient degrees of freedom. This is particularly advantageous for developing economies, for which sufficient statistical data are not available or where the social and economic systems are susceptible to drastic changes such as a coup d'état. In addition, CGE models can easily incorporate dozens of industrial sectors, which would require a large dataset in econometric models.

The CGE models presented in this book have some shortcomings. First, as stated above, the parameters of CGE models are estimated on the basis of data from a single reference year. This means that the parameter estimates may be extremely sensitive to the choice of the reference year. In the case of an economy that suffers significant fluctuations, the reference-year data may not provide a good reference point for our empirical analysis.

Second, estimating the CGE models with a one-year dataset can be compared to taking a still picture of a dynamically evolving reality. That is, inclusion of dynamic components of an economy, such as investment and savings, in a static model based on a static estimation procedure is theoretically inconsistent. In consideration of this shortcoming, dynamic CGE models have been developed where intertemporal resource allocation, such as investment and savings, are established fully on the basis of microfoundations. These dynamic models are discussed in other articles.[3] Our remedy for this shortcoming is discussed in terms of macro closure.

Third, financial/monetary aspects are rarely incorporated into CGE models. As stated above, following the original Walrasian general equilibrium model, most CGE models focus on the real side of the economy; thus, they can deal with economies in terms of only relative prices, not absolute prices.[4] As a result, CGE models cannot deal with monetary phenomena such as inflation or (nominal) foreign exchange rate policy. To overcome this difficulty, a few so-called financial CGE models have been developed; however, these models tend to be so large that they cannot be solved easily, and their simulation results are difficult to interpret. Such financial/monetary CGE models are also referred to in other articles and books.[5]

1.4 Applications of CGE models

Here, we present a list of typical research topics using CGE models, which will help readers to make their own research plans using CGE models.

- General macroeconomic issues: public expenditure cuts, impact of trade and tax reforms on income distribution
- Fiscal policy issues: introduction of value-added taxes, commodity tax reforms
- International trade policy: impact of WTO negotiations, Association of Southeast Asian Nations (ASEAN) free trade area formation, tariffication of rice import barriers
- Regional and transport policy: impact of high-speed rail and highway investment
- Environmental policy: introduction of eco-taxes, implementing a tradable CO_2 emissions permit system
- Industrial and labour policies: deregulation of electric power industry, impact of foreign workforce inflows

Some of these topics may be of interest not only to economists but also to social scientists and even engineers.

1.5 Aims of this book

In this book, we aim to develop the CGE modelling skills of readers so that they can develop and operate CGE models by themselves. In this sense, the book is intended to be a 'how-to'-type textbook. By following the book, readers will learn in a step-by-step manner how to develop CGE models, to compute these models with a PC and to interpret simulation results. The focus on the practical skills and techniques of CGE modelling is a unique feature of this book compared with others.

To accomplish our aim, we develop CGE models by explaining:

(1) How to collect and compile data for construction of CGE models
(2) How to estimate the parameters and coefficients of the models
(3) How to prepare computer programs for numerical simulations