Risk Assessment of Food Supply

Risk Assessment of Food Supply: A Computable General Equilibrium Approach

By

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To my parents

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DR TETSUJI TANAKA

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CHAPTER ONE

INTRODUCTION

TETSUJI TANAKA

Motivation and objective

While it is acknowledged that the occurrence of a food crisis follows roughly a 30-year cycle (Naylor and Falcon, 2010), food prices rose sharply twice in 2008 and 2010. The recent food price rise has pushed 44 million more people into poverty since June 2010 and the food price turbulence in 2008 drove 100 million people into poverty (World Bank, 2011). These two very recent crises may suggest that access to food is becoming more difficult now and in the near future. In addition to the traditional factors of population and income growth in BRICs (Brazil, Russia, India, and China), which would lead to a slow increase in food demand, the striking food price turbulence in recent years may be more closely associated with the following new factors: biofuel production, financial globalisation, expansion of food speculation and climate change, among others.

Biofuel production has grown rapidly over the last ten years. The US and Brazil are large producers of bioethanol, which are produced mainly from maize and sugarcane, respectively. In 2008, over 30% of maize production in the US - the largest producer of maize - went to ethanol factories.[1] The EU is the largest producing region of biodiesel, which is mostly manufactured from soybean and oilseeds. Huge amounts of all grain produced in the world are now used for industrial purposes.

Many multilateral and bilateral free trade agreements have been concluded for agricultural products. While trade liberalisation is said to enhance the efficiency of resource allocation, nations deepen their interdependency on food through these agreements and become more susceptible to shocks from abroad such as poor harvests and embargoes.

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[1] The share of maize used as feedstock in the US is estimated by the author.

Speculation has increased in food markets and was widely criticised as the root cause for the grain price bubble in 2008. Nicolas Sarkozy, the president of France, insisted at the 2011 G20 meeting that “France wants great transparency and regulation of commodities prices and derivative trading to stop being driven by speculation” (Rowley, 2011). Not only the G20 but the Food and Agriculture Organisation (FAO) also points out that speculation is the largest fundamental factor of the recent food crisis (Aloisi, 2011).

Some developing economies such as China and India, the first and second most populous countries in the world, are growing markedly. There is a historical trend that income growth increases meat consumption in terms of total calorie intake. In reality, meat consumption per capita in China grows as its economy develops, according to the FAOSTAT, which suggests that more grain is demanded for livestock feed.

Global food production can be damaged where climate change brings extreme weather pattern. Severe droughts devastated Australia’s crop harvest in 2006 and 2007. Russia and Ukraine’s grain production declined by as much as 38%, and they imposed a ban on their grain exports in 2010, which may have raised the world’s wheat price by 58% according to Madon (2010). In recent years, more floods, droughts, and typhoons seem to have affected agricultural production.

One of the most important new factors is trade liberalisation over agricultural products as agricultural sectors are frequently contentious elements in negotiations of food security. Apart from industrial countries which maintain high food self-sufficiency rate like the U.S or Australia, industrialisation tends to undermine agricultural sectors’ comparative advantage. Even the self-sufficiency rate of those European countries which are considered to be large agricultural regions has been declining since the late 1990s, and Asian countries like Japan, Taiwan and Korea show even clearer declining trends with their economic development. With many developed nations facing difficulty in feeding themselves, it is becoming ever more important to think about agricultural free trade issues from the viewpoint of food security for advanced and emerging nations such as China.

The most archetypal country is Japan. It achieved dramatic economic growth after the Second World War, and its food self-sufficiency rate on a calorie basis was about 80% in 1960, but only 40% after 1998. However, Japan is almost self-sufficient in rice, the primary diet, although the country currently imports 8% for the minimum access opportunities of the World Trade Organisation (WTO). This is a result of the strict protection by a high tariff of around 800%. Japan has long been called on to abolish the high tariff on rice by other countries, but has refused for its food security concern.

As stated, food interdependency between countries can facilitate the international transmission of food prices by lowering trade barriers. The world food market volatility in 2008 immediately spilt over to the economies of various regions, and some countries implemented grain export restrictions to curb domestic prices, which made the international market tighter and drove food prices several times higher. As a consequence, riots occurred in many areas of the world. In 2009, after the food crisis, a G8 summit was held to find international consensus on food price stabilisation policy. However, the effectiveness of these policies is in doubt because the fundamental causes behind the food price spikes were not yet fully clarified. Hence, it is essential to evaluate the impacts of potential risk factors on the world market's food prices.

A major question which agricultural and development economists have long struggled to answer is whether or not high agricultural prices are beneficial for developing economies (Aksoy and Izik-Dikmelik, 2008; Ivanic and Martin, 2008; Barrett and Dorosh, 1996; Ravallion and Lokshin, 2005). There are many publications on this subject, but the fundamental causes of grain price rises in poor countries have not been sufficiently examined. This is despite the fact that the rampages of the 2008 food crisis happened only in destitute regions, which implies that people in the developing world suffered more severely than those in rich economies.

As has been noted, developed and developing countries have individual factors for food security. This book evaluates the impacts of potential risk factors on food prices, and identifies policy implications for stabilising the food market. It does this through three empirical studies: one focusing on assessing the effects of rice trade liberalisation in Japan; a second identifying the underlying factors of the 2008 food price spikes, and a third establishing the contributory factors behind grain price rises in the least developed countries (LDCs).

Methodological issues

Computable general equilibrium (CGE) models are employed in the book. These are based on the general equilibrium framework developed by L. Walras and rooted in the work of Johansen (1960) who is widely regarded to have established the first CGE model. They have mainly been used in the areas of international trade, agriculture, development and environment.

CGE is suitable for agricultural research as agricultural sectors have become more deeply related to other sectors such as energy in recent years. Biofuel production from food materials such as maize, sugarcane, and oilseeds grew rapidly in the last decade. It can also influence the oil price as a substitute, and this affects agricultural production for intermediate input. Given this context, models that can capture the interactive effects between the industries are needed to analyse agricultural and/or food sectors. Hence, CGE can be a powerful tool in these research fields.

Another reason is the convenience of building a world-scale model. All three research topics in the book are relevant to international trade, which means that a global trade model is indispensable. Generally, collecting data to develop international models takes considerable costs, but for over a decade the Global Trade Analysis Project (GTAP) has contributed to a dataset called a social accounting matrix (SAM) for world models (Hertel, 1997). The GTAP's latest version of the global SAM has 113 regions of the world and 57 sectors. Today, the international interactive effects cannot be overlooked, taking into account the unification of European countries and lower trade barriers between countries. For this reason, it is appropriate to apply CGE models to the agricultural policy issues addressed in the book.

On the other hand, an often noted major weakness of CGE models is the unreliability of parameter estimation. In the process of building CGE models called "calibration", various parameters are estimated from the SAM used in the study.[2] A SAM is composed of a single-year data, which suggests that the parameters heavily depend on the year of a SAM. Conversely, this is an advantage of CGE models, and is a reason for which CGE is often used in development research in which data is often difficult to be collected. Yet, Valenzuela and Hertel (2007), for example, have demonstrated the validity of CGE models in the field of agriculture with some other publications also examining the reliability of the performances of CGE models in energy and international trade (Beckman et al., 2011; and Hertel et al., 2007).

Note on the database

The primary data set for the book is the global SAM from the GTAP. The latest version 7.2 of the GTAP has 57 industrial sectors and 113 regions, which are aggregated according to the purpose of the research. Elasticity of substitution is essential in CGE analysis. Most elasticity values are cited from the GTAP database although some elasticities

[2] See Section 2.5 for calibration.

estimated econometrically by existing literature are applied to the model.

Biofuel sectors do not exist in the latest GTAP database. For the purpose of this research, we need to introduce bioethanol and biodiesel sectors into the original database by estimating the relevant values of the sectors partly following the technique of Taheripour (2007). This article uses software called “SplitCom” to make new sectors in the GTAP database, but we insert them into the original data on our General Algebraic Modelling System (GAMS) programme.[3]

The SAM used in the book is based on 2004. The base year of CGE analysis is required to be in a situation like “equilibrium”. The IMF Commodity Prices indicate monthly time-series world agricultural prices in which food prices do not show large price volatilities over the year of 2004. Thus, it can be considered that the GTAP database version 7 meets the conditions for being the base year of our analyses.

Contributions of the research

This book makes a methodological contribution and identifies several policy implications. First, most studies on Japan’s rice trade liberalisation examines deterministic effects by a partial and general equilibrium model. Yet, for the empirical study in Chapter 3 we develop a stochastic CGE model with the Monte Carlo method to make it possible to assess the probabilistic impacts of rice productivities, which enables us to answer how risky rice trade liberalisation is for Japan. The Monte Carlo estimation in CGE is unconventional, and can make a solid contribution to the area.

Some important policy implications are noted by the book. On the topic of the Japanese government’s rice trade liberalisation policy, existing articles focus on deterministic gains/losses (Cramer et al., 1999; Cramer et al., 1993; Wailes, 2005) but fail to answer a serious concern in Japan that rice export embargoes may be carried out by export partners after relying more on imports. Our study overcomes the long-standing problem by developing a stochastic CGE model.

Many reports explore the possible factors behind the food crisis in 2008. However, most employ a descriptive method. Some articles estimate the impact of export restrictions, oil price hikes and biofuel production (Charlebois, 2008; Yang et al., 2008; Mitchell, 2008; and Rosegrant, 2008) but other factors such as crop failures by drought are not investigated. In addition, it is important to assess the effects of potential factors in one

[3] The GAMS is a programming language. This is more explained in Chapter 2.

model in order to compare the magnitude of influences. We identify the risk factors, measuring the effects of poor harvests in Australia and Ukraine, export restrictions by major exporters, the oil price spike and biofuel production.

Analyses of the relationship between high food prices and poverty in developing countries can be roughly classified into three groups. The first category considers whether high food prices increase poverty in developing countries (Aksoy and Izik-Dikmelik, 2008; Ivanic and Martin, 2008; Barrett and Dorosh, 1996; Ravallion and Lokshin, 2005). The second examines the price transmission from global to regional markets (Arndt et al, 2009 and Cudjoe et al., 2010). The final group clarifies factors threatening domestic markets in developing economies (Yang et al., 2008; Nganou et al., 2009; Parra and Wodon, 2008). These studies analyse the impacts of high oil price and biofuel on food price in a specific country like China and Kenya. However, the investigated regions are not extremely poor countries such as those least developed countries (LDCs) which suffered more severe damages from food inflation. Therefore, we will clarify how much the risk factors affected the 2008 price spikes in LDCs.

Organisation of the book

Chapter 2 describes the methodology used for the studies by explaining the structure of SAMs, CGE models and the Monte Carlo method. Chapter 3 analyses Japan's rice trade liberalisation policy. Chapters 4, 5 and 6 contain two types of analyses: the analysis of the factors underlying the food price increases in the world markets; and the identification of potential determinants of the grain price rises in LDCs. Chapter 4 gives the introduction and literature survey. Chapter 5 conducts a critical review of the models in the past literature, and explains our methodology. Chapter 6 shows the simulation results and discusses the policy implications. Finally, Chapter 7 concludes the whole book.

CHAPTER TWO

COMPUTABLE GENERAL EQUILIBRIUM MODEL

TETSUJI TANAKA

Introduction

The general equilibrium theory developed by L. Walras was refined by K. Arrow and G. Debreu to discuss the existence and the stability of competitive equilibrium. However, their models are abstract and so cannot be applied to real economic problems. As explained below, the general equilibrium theory has evolved to become a useful tool for policy analysis, used by many economists.

Figure 2.1 shows the basic idea of a CGE model. Households supply their factors of production such as labour and capital to the market while firms demand them for their production. Firms produce commodities and services, and households consume them. The demand and supply of production factors and commodities are adjusted on markets through the price mechanism. Households and firms maximise their utility and profit under the budget constraint and production technology, respectively.

CGE models originated from input-output (IO) models developed by Wassily W. Leontief, although price and quantity are not independently endogenous in IO models.[1] The prototype of CGE models is Johansen (1960) and Harberger (1962). Furthermore, Scarf (1967), who numerically solved the Arrow-Debreu general equilibrium, contributed to developing various applications of the models. Dervis et al. (1982) constructed CGE models for developing economies, whilst models for tax and international trade issues in advanced countries were built by Shoven and Whalley (1992). Although the models can be applied to a wide range of areas, most models have been made for international trade. The GTAP model and

[1] Exactly, applied general equilibrium (AGE) models are not identical to CGE models. Yet, for simplicity both are standardised to CGE in this book. See Mitra-Kahn (2008) for more explanations.

database, a global CGE model and SAM, have played a great role in the development of trade policy analysis (Hertel, 1997).

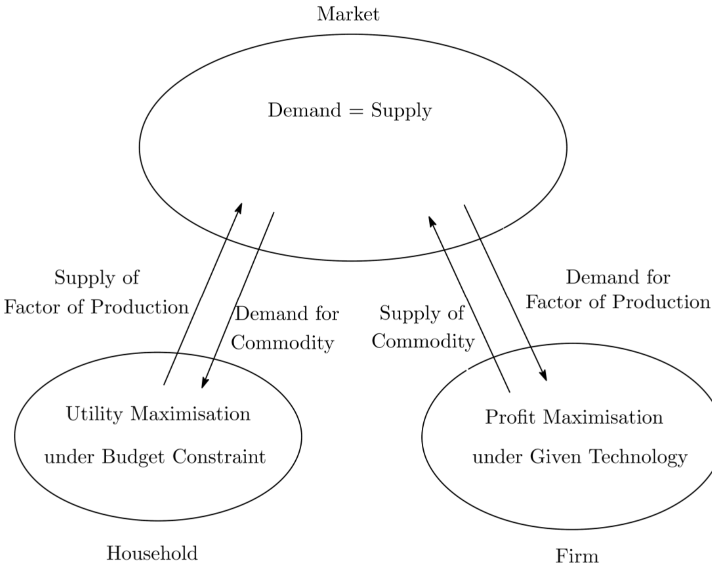

Figure 2.1: Concept of a CGE model

Whalley (1982) conducted one of the pioneering works analysing trade policies using the general equilibrium frame work in a numerical fashion. It evaluates the effects of the various formulae proposed in the Tokyo Round negotiations under the General Agreement on Tariffs and Trade (GATT). CGE models have since been more widely used to discuss multi-regional trade issues with the GTAP model and database as described. Initially, it was often applied to the North American Free Trade Agreement (NAFTA) and multilateral trade negotiations under the GATT/WTO. Many of the important articles on the NAFTA and the Uruguay Round analysed by CGE are introduced by Francois and Shiells (1994) and Martin and Winters (1996), respectively.

Studies scrutinising the international trade issues are categorised roughly into five groups: reduction/abolishment of trade barriers for industrial products; trade barriers/subsidy for agricultural products; trade barriers for service sectors; trade facilitation; and others such as foreign direct investment and the liberalisation of capital and labour mobility. The third and fourth categories, trade barriers for service and trade facilitation, are more difficult to analyse in terms of quantifying the trade barriers. The estimates of the barriers differ greatly between papers because the data and methods for the estimation used are not agreed. This is still an important subject in this area.

While the GTAP model is regarded as a standard model in international trade CGE analyses, the Michigan model by University of Michigan and the Francois model by Francois into which economies of scale and imperfect competition are introduced were built with the development of the new trade theory by Krugman (1980).[2] The Francois model has a similar structure to the GTAP model but discards the Armington assumption. In the Michigan model, the Cobb-Douglas utility function is employed, and the Armington assumption is not made. Also, recursive dynamic models such as the LINKAGE model by the World Bank and the MIRAGE model by the Centre d'Etudes Prospectives et d'Informations Internationals (CEPII) have since been constructed.[3] The LINKAGE model adopts the perfect competition assumption while the MIRAGE model assumes imperfect competition and economy of scale.

Given the specific topics of this book, rice trade liberalisation in Japan and the grain price rises in the world market and LDCs' economies, some major strengths and weaknesses of CGE analyses should be mentioned. First, a CGE model can capture the spillover effects of the paddy and processed rice trade liberalisation on other various sectors such as service sectors, which is important especially when evaluating household welfare changes related to a variety of consumption goods and services. Second, it can consider repercussion effects. Today, food security has a complex structure with agricultural production, biofuels, oil, fertiliser and transport, which are related to each other. The complicated structure is well expressed on an IO data matrix. Hence, CGE simulations have an advantage. On the other hand, a weakness is that if import share is zero in the base data, the import remains zero even after abolishing trade barriers, which means that if Japan did not import rice from country A in the base year, the country does not export it to Japan after liberalisation. This suggests the possibility of the overestimation of the negative impacts on household welfare. Another disadvantage is that CGE cannot explicitly consider financial markets. Therefore, although financial speculation and

[2] See Hertel (1997), http://www.fordschool.umich.edu/rsie/model/ and Francois and Roland-Holst (1997) for the information on the GTAP, Michigan and Francois models.

[3] See Mensbrugghe (2005) and Bchir et al. (2002) for the LINKAGE and MIRAGE models.

US dollar depreciation are considered to be important potential factors for the world's grain price spikes, their effects cannot be quantified directly by CGE models. To overcome this difficulty, financial CGE models have been developed, but they are not sufficiently applicable yet.

We will discuss rice trade liberalisation in Japan in Chapter 3. This is a long-debated issue, but still Japan's government imposes very high tariffs on rice imports to protect domestic rice farmers. Economists have struggled to demonstrate benefits or losses from liberalisation. However, one of the largest unanswered questions is whether or not Japan secures reliable food supply by liberalising the rice market. To assess the risk, we develop a stochastic CGE model using the Monte Carlo method, and answer the question in Chapter 3.

A CGE model is formulated as a nonlinear programming problem or nonlinear simultaneous equations. To solve this problem, we use the General Algebraic Modelling System (GAMS). The GAMS was developed by the World Bank to analyse developing economies (Hosoe et al., 2010). The main features are that it is possible to directly programme algebraic equations and it has powerful algorism to solve complex problems. Thus, GAMS has been a standard language for CGE modellers.

In this chapter, firstly the structure of a SAM will be explained using a simple and global SAM composed of the GTAP database. Next, we will introduce a standard static single-country CGE model. Then, the model is extended to a global scale. Finally, the modifications of the world model for the empirical studies of this book are delineated.

Social accounting matrix (SAM)

Simple social accounting matrix

A SAM describes commodity and monetary flows of an economy for a certain period (usually one year). It is based on the input-output table developed by Wassily W. Leontief, and is constructed by combining an IO table with some additional data such as household savings.[4] The total of each heading is equal, suggesting demand and supply (or revenue and expenditure) are balanced. Like an IO table, the columns and rows of a SAM represent buyers and sellers, which mean that commodities flow from the column to row headings, and monetary flows conversely go from the row to column headings.

[4] Regarding the way of construction, see Hosoe et al. (2010).

Table 2.1: Example of a social accounting matrix

Unit: £

		Production Activities		Production Factors		Indirect Tax		Final Consumption			Foreign Countries	Total
		Wheat	Rice	Capital Stock	Labour	Production Tax	Import Tariff	Household	Government	Investment		
Production Activities	Wheat	12	30					38	2	1	7	90
	Rice	13	17					60	4	10	8	112
Production Factors	Capital Stock	10	9									19
	Labour	45	42									87
Indirect Tax	Production Tax	2	4									6
	Import Tariff	3	2									5
Final Consumption	Household			19	87							106
	Government					6	5	5				16
	Investment							3	10		-2	11
Foreign Countries		5	8									13
Total		90	112	19	87	6	5	106	16	11	13	

Table 2.1 shows a simplified SAM. The table includes the following sections: production activities, production factors, indirect tax, final consumption, and foreign countries.

Final consumption

In Table 2.1, (Wheat, Household) signifies that households consume £38 worth of wheat, and that wheat producer receives £38 from households.[5] In the same way, (Rice, Household) indicates that households consume £60 worth of rice, and that rice producers are paid £60 by households. Similarly, (Wheat, Government) and (Wheat, Investment) displays that £2 and £1 worth of wheat are consumed by the government and the investment (investor), which pay the money to producers.

Production activities

In the table, (Production Activities, Production Activities) shows intermediate input. (Rice, Wheat) demonstrates that £13 worth of rice is input into wheat production, and that rice producers receive £13 for offering rice from wheat producers. Likewise, £30 and £17 worth of wheat and rice are used for rice production, and wheat and rice producers receive £30 and £17, respectively.

Factors of production

The factors of production in the table are labour and capital stock. (Capital Stock, Wheat) shows that £10 is paid to owners of capital such as tractors by wheat farmers for lending the tractors. (Labour, Rice) also designates that people who worked for rice production receive £42 from rice producers for offering labour force.

The cell (Final Consumption, Production Factors) suggests the income of each economic agent such as household, government, and investment. For instance, households supply £45 and £42 worth of labour force to wheat and rice production, respectively. The total amount of income is displayed in the cell (Household, Labour) and (Household, Capital), which are £87 and £19, respectively. The income of the government is tax revenue. The cells (Indirect Tax, Production Activities) go to the government. For instance, the production tax for wheat and rice are £2 and £4, respectively. The total production tax revenue is displayed in the cell of (Government, Production Tax), which is £6. The sources of revenue for investors are the savings of the household, government, and foreign countries. They are described in the cell of (Investment, Household),

[5] In this chapter, (x,y) is x=row and y=column.

(Investment, Government), and (Investment, Foreign Countries), which are £3, £10, and -£2, respectively.

Indirect tax

Indirect tax is imposed on productions. For example, (Wheat, Production Tax) shows that wheat producers pay £2 to the government. (Wheat, Import Tariff) indicates that £3 is paid to the government when importing wheat from other countries.

Foreign countries

The cell (Foreign Countries, Rice) shows rice imports from abroad: the country imports £8 worth of rice from other countries. The imported commodities are used for both intermediate inputs and final consumption. The cell (Rice, Foreign Countries) signifies rice export. It shows that £8 worth of rice is exported to foreign countries.

IO tables are usually updated once in several years by national governments. If one needs a particular year-base SAM, he can update it using the RAS method.[6] The next section will extend it to a world scale using the GTAP database.

Global social accounting matrix with the GTAP database

The previous section outlined a basic single-country SAM. An international SAM differs particularly in trade sectors, but the commodity/service and monetary flows can be read in the same way. This section describes the structure of a global SAM fed with the GTAP database.

Table 2.2 indicates the structure of an international SAM composed of the GTAP database. The unit of value is in millions of US dollars in the GTAP database. The necessary data provided by the GTAP database for a world SAM is shown in Table 2.3.[7] The dimensions are different from those of the single-country SAM shown in the previous section (Table 2.4). The additional data are export duties, factor use taxes, transport margins on imports, exports of transport services and trade balance. The export duties are generated with exports; these are often negative values in agricultural sectors and mean export subsidy. The factor use taxes are imposed on labour, capital, farm land, and natural resources. In the GTAP

[6] RAS stands for Richard A. Stone who established the approach to update IO tables. See Parikh (1979).

[7] See McDonald and Thiefelder (2004) for constructing a SAM with the GTAP database.

SAM Table 2.2: Structure of a global GTAP with the database

	Production Activities	Factors	Production Taxes	Import Tariff	Export Tax	Factor Taxes	Household	Government	Investment	International Transport	Foreign Countires
Production Activities	Intermediate Inputs +Supply Matrix						Private Demand	Government Demand	Investment Demand	Exports of Transport Services	Exports of Goods and Services
Factors	Payments to Factors										
Production Taxes	Production Taxes										
Import Tariff	Import Duties										
Export Tax	Export Duties										
Factor Taxes	Factor Use Taxes										
Household		$\sum Payments$									
Government			$\sum Production\ Taxes$	$\sum Import\ Duties$	$\sum Export\ Duties$	$\sum Factor\ Use\ Taxes$	Direct Tax				
Investment							H.hold Saving	Gov. Saving		Trade Balance	Foreign Saving
International Transport	Transport Margins on Imports										
Foreign Countires	Imports of Goods and Services										

database and model, the international transport sector is considered, which suggests that transportation fees are levied with the transaction of imports/exports. So, importers pay a fee for their imports to international transport service firms, and this appears in transport margins on imports. Contrarily, companies exporting global transport services receive a fee from importers, which is expressed on export of transport services.

Table 2.3: Data for constructing a global SAM provided from the GTAP database

Supply Side	Demand Side	Others
Supply Matrix	Intermediate Inputs	Household Saving
Payments to Factors	Private Demand	
Production Taxes	Government Demand	
Import Duties	Investment Demand	
Export Duties	Exports of Transport Services	
Factor Use Taxes	Exports of Goods and Services	
Transport Margins on Imports		
Imports of Goods and Demands		

Table 2.4: Dimensions of the elements in the GTAP database

Dimension (j,r)	Dimension (j,r,s)	Dimension (r)	Dimension (i,j,r)	Dimension (h,j,r)
Production Taxes	Import Duties	Household Saving	Supply Matrix	Payments to Factors
Private Demand	Export Duties		Intermediate Inputs	Factor Use Taxes
Government Demand	Exports of Transport Services			
Investment Demand	Exports of Goods and Services			
	Transport Margins on Imports			
	Imports of Goods and Demands			

Note: i, r, and h signify goods and services, regions, and factors, respectively. j and s are the alias for i and r.

To make a completed intermediate input matrix, an intermediate inputs matrix and a supply matrix are doubled. In the same way as the simple SAM, payments to factors are added to make the total income for households (Household, Factors). Taxes imposed on production, import, export, and factor use are also added to make the tax revenue of the government ((Government, Production Taxes), (Government, Import Tariff), (Government, Export Tax), and (Government, Factor Taxes)). Given household saving data, direct tax is estimated by:

$\sum$ Payments – (Private Demand + H.hold Saying)

Then, Trade balance and foreign saving are computed by (Transport Margins on Imports–Exports of Transport Services) and (Imports of Goods and Services –Exports of Goods and Services). Similarly, government saving is calculated by (Investment Demand – Foreign Saving – Trade Balance – H.hold Saving).

CGE model

A single country CGE model

In this section, we will give information on a standard static single-country CGE model.[8] Figure 2.2 is the model structure for one sector. We will explain from the bottom to the top.

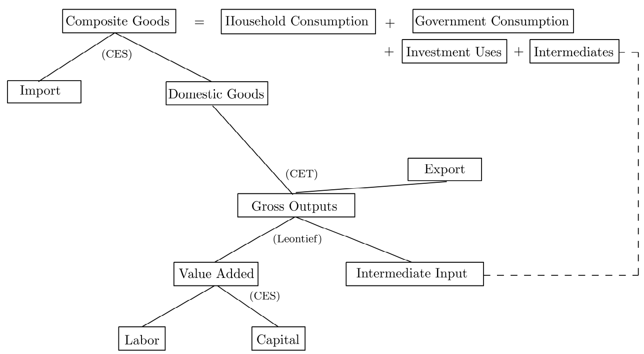

Figure 2.1: The structure of a single-country CGE model

Intermediate input (Equation (2.1.)-(2.6.))

Factors of production such as labour and capital are combined to produce a composite commodity of production factor (Equation (2.1.)). A firm varies the input ratio between labour and capital in response to the relative price so that the domestic representative firm maximises its profit. The function is a constant elasticity of substitution (CES) form here, but the Cobb-Douglas form is also often applied. The factor composite commodity is input with the intermediate inputs for domestic production (Equation (2.5.)). The production function is the Leontief form (Equation (2.3.)).

[8] See Hosoe et al. (2010) for the application of a SAM to a CGE model.

-Value added producing firm Factor demand function

$$F_{h,j} = \left(\frac{b_j^{\eta_j^{va}} \beta_{h,j} p_j^y}{p_{h,j}^f} \right)^{\frac{1}{1-\eta_j^{va}}} Y_j \qquad \forall j \quad (2.1.)$$

Value added production function

$$Y_j = b_j \left(\sum_h \beta_{h,j} F_{h,j}^{\eta_j^{va}} \right)^{1/\eta_j^{va}} \qquad \forall j \quad (2.2.)$$

-Gross output producing firm

Production function: $Z_j = \min\left(\frac{X_{i,j}}{ax_{i,j}}, \frac{Y_j}{ay_j} \right)$ $\forall j$ (2.3.)

Demand function for intermediates

$$X_{i,j} = ax_{i,j} Z_j \qquad \forall i, j \quad (2.4.)$$

Demand function for value added

$$Y_j = ay_j Z_j \qquad \forall j \quad (2.5.)$$

Unit price function

$$p_{j,r}^z = ay_j p_j^y + \sum_i ax_{i,j} p_i^q \qquad \forall j \quad (2.6.)$$

Sets

i, j : commodities/sectors

h : factors (capital (CAP), land(LAN), labour(LAB))

Variables

Y_j : value added

$F_{h,j}$: factor uses

Z_j : gross output

$X_{i,j}$: intermediate uses of the i-th good by the j-th sector

p_j^y : price of value added

$p^{f}_{h,j}$: price of factors

p^{z}_{i} : price of gross output

p^{q}_{i} : price of Armington composite goods

Parameters

b_j : scale parameter of production function for Yj

$\beta_{h,j}$: share parameter of factor input

σ^{f}_{j} : elasticity of substitution for a value added composite function

$ax_{i,j}$: share parameter of intermediate input for domestic production

ay_j : share parameter of composite factor input for domestic production

η^{va}_{j} : elasticity parameter $\eta^{va}_{j} = \dfrac{\sigma^{f}_{j} + 1}{\sigma^{f}_{j}}$

International trade (Equation (2.7.)-(2.15.))

Products produced by the representative firm are allocated to foreign countries (export) or to the domestic market. At this stage, we assume a firm converts the products according to the needs of the domestic market or the international market. It is also assumed that the company responds to the relative price changes between international and domestic goods. The sensitivity of the reaction to the prices is described by the elasticity of transformation. When a UK car company, for example, makes its cars, they would attach more functions to the vehicles exported to Japan responding to Japanese preference. The more changes firms add to their products for export, the more cost is entailed. So, if the quality of products differs greatly between domestic sales and exports, the elasticity of transformation is relatively low.

Products allocated for domestic sales are combined with imported products with a CES function to make a composite commodity for domestic consumers such as household, government, investment, and intermediate inputs for other sectors. It is easier to understand by imagining that a firm mixes long-grain with short-grain rice to sell on the domestic market. If a rice crop failure occurred in a country, the relative price would be changed,