

Using GAMS for Agricultural Policy Analysis

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SECTION 1: INTRODUCTION TO THE TRAINING GUIDE

Objectives

The objective of this training module is to explain how to use GAMS to construct, calibrate, and modify agricultural sector models in order to simulate the effect of alternative policies or other events affecting agricultural markets. In particular, the course aims to train the participants in the following skills:

- determining whether an agricultural sector model is appropriate for a given research question;
- selecting the scale of the model in terms of commodities, markets, and time periods;
- constructing the model in GAMS using available data ;
- running simulations of alternative policies and events;
- revising the model in response to new information; and
- documenting and describing the results of simulations.

Although the course does not attempt to cover agricultural economics and international trade in depth, it does provide a quick review of concepts to explain the logic behind the components of agricultural sector models.

It should be noted that this course is not a lecture course, but rather it is a semi-structured hands-on workshop in which trainees will use computers to learn different methods of analyzing data. The course starts out with very simple models and gradually introduces new concepts and new commands to develop a multimarket spatial equilibrium model that represents four commodities and six regions, as well as internal trade and international trade. This model is called SDP4 and is shown in Annex 1 of this guide.

Organization of the course

The training course is divided into ten sections. We will cover some material in all 10 sections, but we may not be able to cover all the material, depending on the background of the trainees.

Section 1: Introduction to the training guide

Section 2: Introduction to agricultural sector models

Section 3: Introduction to GAMS

Section 4: Modeling demand

Section 5: Modeling supply

Section 6: Equilibrium for non-tradable goods

Section 7: International trade

Section 8: Regional trade

Section 9: Income and welfare effects

Each section includes a quick review of relevant economic concepts, training in the use of GAMS, and a number of practical application of these commands using simple models of agricultural markets. The practical applications are taught using a set of about 20 simple agricultural models, starting with very simple models and working up to a four-commodity, six-region spatial equilibrium model. This model, called SDP4, is shown in Annex 1 of this guide. This model is also used throughout the guide as an example of the use of different GAMS commands.

SECTION 2: INTRODUCTION TO AGRICULTURAL SECTOR MODELS

Definition of an agricultural sector model

An *economic model* is defined as a set of equations designed to simulate the supply and demand for different goods and services. These models are used to predict the likely effect of changes in external factors (such as changes in policy, world prices, and technology) on prices, production, consumption, trade, and income.

Models of agricultural markets focus on the supply and demand of crops and livestock, and sometimes the use of factors of production (land, labor, and capital) and the income of agricultural households. These agricultural models¹ differ somewhat from economy-wide models or models of other sectors because of some distinctive characteristics of agricultural products:

- Agricultural products are characterized by a high degree of substitutability in production and consumption. This implies that the markets are more closely linked to each other than in many non-agricultural sectors.
- Crops generally have low value/bulk ratios, so that there is greater spatial variation in crop prices than in other prices.
- Most agricultural products are perishable, so there is more seasonal variation in agricultural prices than in non-agricultural prices.

Agricultural models are an important tool in agricultural and food policy analysis. They are particularly useful in developing areas because of the a large percentage of the population that depends on agricultural production for its livelihood. In addition, food expenditures represent a large share of household budgets in developing countries. Agricultural models are useful in understanding the effects of policy, technology, and world prices on the poor, because the bulk of the poor in most developing countries are farmers and because poor consumers devote a particularly large share of their budgets to food purchases.

Agricultural models can be used to address questions such as:

- what is the effect of an import tariff on rice on domestic rice prices and farm income?
- how will restrictions on internal movement of food grains affect prices in different regions?
- if the price of maize increases, what will be the effect on the production and price of meat?
- how large would a national grain reserve need to be in order to keep prices from rising above a certain level? and
- how will the adoption of a new high-yielding variety of maize affect output, prices, and farm income?

Like all models, they are only as good as the assumptions used in constructing them. It is sometimes said that the value of a model is that it tells you the logical consequences of your assumptions.

¹ For convenience, we use the term “agricultural models” to refer to economic models of the agricultural sector, excluding non-economic models such as those relating climate to crop production.

Key concepts in modeling

Before proceeding, it is useful to define some a few modeling terms that are used in this paper. Mathematical models are constructed from parameters, exogenous variables, endogenous variables, and mathematical expressions.

Parameters (or coefficients) are fixed values that describe the effect of one variable on another variable. Elasticities of supply and demand are common types of parameters in economic models.

Exogenous variables are those that are fixed, meaning that they do not change within the model. Rainfall, world prices, the supply of land, technical efficiency, and marketing margins are often considered exogenous variables in agricultural model².

Endogenous variables are those whose values are determined within the model. Variables that are typically endogenous include prices, production, consumption, imports, and exports. However, models differ in their assumptions about which variables are endogenous and which are exogenous. For example, some models assume the supply of labor is fixed (exogenous), while others assume that the supply of labor varies with the wage rate, making it endogenous.

Mathematical equations are equalities and inequalities that describe the relationships among the variables. For example, an equality may describe the demand for rice as a function of the price of rice and the income of consumers. An inequality may describe the fact that the domestic price of rice will generally be less than or equal to the cost of importing the same quality of rice (including tariffs and transportation cost).

Solving a model is to find the values of the endogenous variables that satisfy all the equations and constraints. The solution is the output of the model.

An important point is that, in order to solve a model, *the number of endogenous variables must be equal to the number of equations*³. If the number of equations is greater than the number of endogenous variables, in general, there is no solution. To take a trivial example, assume that demand is fixed at 100 tons, and supply is fixed at 50 tons. There are two equations ($Q=100$ and $Q=50$), but only one endogenous variable (Q) and no solution.

If, on the other hand, the number of equations is less than the number of endogenous variables, the model will generally have infinite solutions. To take another trivial example, if we have one demand equation with two endogenous variables, demand and price, it is not possible to solve the model for the values of demand and price. If we add a second equation, a supply equation, then the number of equations and endogenous variables match and there is a unique solution.

Types of agricultural sector models

There is a wide range of different types of agricultural sector models. Although there is no standard system for classifying them, it is possible to describe various dimensions along which agricultural models may differ. Below we list seven key dimensions of economic models:

- the number and types of commodities
- single-region vs multiple-region models

2 Mathematically, there is little difference between parameters and exogenous variables, but parameters represent relationships between variables, while exogenous variables are economically relevant concepts. Parameters are assumed to be fixed over time, while exogenous variables vary in real life, but are assumed constant in the model. Finally, parameters are estimated econometrically, while exogenous variables are typically measured directly.

3 This rule is complicated by the fact that the number of equations in a model varies depending on how it is expressed. A single market can be expressed as three equations ($S = a + bP$; $D = c + dP$; and $S=D$) or as two equations ($Q = a + bP$; $Q = c + dP$) or even as one equation ($a + bP = c + dP$). Fortunately, the number of endogenous variables declines from 3 to 2 to 1 at the same time, maintaining the equality between equations and endogenous variables.

- non-spatial vs spatial models
- static vs dynamic models
- deterministic vs stochastic models,
- partial vs general equilibrium models, and
- optimization vs equilibrium models.

Below, we describe each of these dimensions in turn.

The first dimension concerns the *number of commodities*. At one extreme, some models focus on a single commodity, although it may represent several different quality types of that commodity. This does not necessarily mean they are simple models; they may represent global trade for that commodity with detailed treatment of tariffs, non-tariff barriers, domestic agricultural support policies, and different grades of the commodity. An example is the Arkansas Global Rice Model, a dynamic non-spatial model developed and maintained by the University of Arkansas (Fuller et al, 2004). At the other extreme, large computable general equilibrium (CGE) models may have more than 50 sectors. For example, Harrison et al (2001) reports on the results of simulations using a 54-sector CGE model of the Chilean economy.

A second way to distinguish agricultural models is according to the *number of “regions”* represented in the model, where a region can represent any spatial unit such as a district, province, country, or group of countries. Many models simulate markets in just one region, typically a country, though they may include trade with the rest of the world. Multi-region models can simulate markets in different locations within a country or different countries. Global models often divide the world into between five and 50 regions and are used to simulate the effect of trade liberalization, climate change, or other global trends. For example, the International Food Policy Research Institute (IFPRI) uses a model called the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) to make projections about food and agriculture over several decades. This model has 43 countries and regions (Rosegrant et al. 2005).

The third dimension is *non-spatial* and *spatial models*. A non-spatial model is one in which the prices for each commodity are the same throughout the model or there are fixed margins between the prices of each pair of regions. Thus, a single-region model is necessarily non-spatial, but a multi-region model may be spatial or non-spatial. If prices are the same across regions, this implies that transportation costs are zero. If there are fixed price margins between each pair of regions, this implies that one of them always exports and the other always imports, so the direction of trade is fixed. In contrast, a spatial model has multiple regions, positive transportation costs, and the direction of trade between each pair of regions is not fixed. Virtually all general equilibrium models and most partial equilibrium models are non-spatial. On the other hand, Minot and Goletti (1998) use a spatial model of food markets in seven regions of Vietnam to simulate the impact of rice export quotas and restrictions on internal movement of rice.

The fourth distinction among models is that between *static* and *dynamic* models. Static models simulate a single period in time. There is a base scenario, usually representing a recent year. A change in policy or technology is introduced and the new equilibrium is compared to the old equilibrium. In a dynamic model, multiple periods are simulated by the model. Dynamic models may take into account the effect of investment in one period on production in the next period, or they may incorporate decisions about storage and inventory, or they may introduce random weather shocks each year to simulate the effect of weather on production and prices. The IMPACT model is a recursive⁴ dynamic model that uses assumptions about changes in

4 In a recursive dynamic model, events at time t influence events in time $t+1$, but not the reverse. This type of model can be solved using a programming loop, where the solutions for each period feeds into the information used to solve the next period. A non-recursive dynamic model, events in time $t+1$ influence events in time t . This could be used to represent rational expectations regarding prices by farmers. These models are more difficult to program and rare in applied policy analysis.

technology and per capita income to project output and prices several decades into the future (Rosegrant et al, 2005). Traditionally, most models have been static, but dynamic models are becoming more common.

The fifth dimension is between *deterministic* and *stochastic* models. In a deterministic model, the initial conditions are fixed and the solution is the same each time the model is run. A stochastic model, in contrast, has one or more random component built into it, so it generates a different solution each time the model is run. Thus, the results are expressed as a distribution of the endogenous variables. For example, an agricultural model may include rainfall as a stochastic variable, with prices being high after a low-rainfall year and vice versa. The model would then “predict” the statistical distribution of the price in a given year (e.g. mean, variance, and probability of the price falling in a given range).

The sixth way of classifying models is between *partial equilibrium* and *general equilibrium* models. Partial equilibrium models simulate one component of the economy, such as one commodity or the agricultural sector. Income is at least partly exogenous. By contrast, a general equilibrium model includes all sectors of the economy and income is fully endogenous. The production of goods and services is linked to demand for factors of production, including labor and capital. The income from factor payments determines household income, which in turn influences the composition of final demand for goods and services. Computable general equilibrium (CGE) models are typically fairly large and complex, typically involving hundreds of equations and parameters.

The seventh and final way of categorizing models is between *optimization* models and *equilibrium* models. In an optimization model, the goal is to maximize (or minimize) an expression, called the objective function, while respecting a series of constraints or inequalities. For example, one common type of optimization model is the transportation model, which minimizes the cost of transporting goods from one place to another subject to alternative shipping routes with associated costs. Another example of an optimization model is the farm model, which maximizes profit subject to various constraints. In contrast, an equilibrium model has a set of equations that must be satisfied, but it does not have an objective function to maximize or minimize.⁵ Before 1980, almost all economic models were based on linear programming, in which the goal is to maximize a linear expression as a function of linear constraints. Since then, software development has made it possible to solve non-linear programming models and a wide variety of linear and non-linear equilibrium models.

⁵ The distinction between the two types of models is somewhat artificial because many optimization models can be expressed as an equilibrium model and vice versa. For example, the objective function in an optimization model can be replaced by a set of first- and second-order conditions, which are equalities and inequalities.

SECTION 3: INTRODUCTION TO GAMS

Key Words

GAMS, parameters, variables, equations, program files, input, output, and the GAMS commands PARAMETERS, VARIABLES, EQUATIONS, MODEL, and SOLVE.

What is GAMS?

GAMS is a software package for designing and solving various types of models. GAMS stands for General Algebraic Modeling System. It was developed by economists at the World Bank for economic models, but it can be used to solve systems of equations from any field of study. GAMS takes a program file as input and sends the results to an output file.

There are two parts to GAMS.

- First, the core of GAMS is just a language for defining the variables and equations in a model. This “language” has ways of describing any equation, even very complicated equations, in an ordinary text file (ASCII format).
- Second, there is a set of solvers, each of which is a complex program for finding the solution to a specific type of problem. Some solvers only do linear programming, some will do non-linear programming, and others will solve different types of equilibrium models.

To create and run a model, we need to learn how to use the language to describe our model, and we need to know which solver will work with our model. In this manual, we will be using equilibrium models with both equalities and inequalities.

Starting GAMS

To open GAMS, double-click on the GAMS IDE icon. The opening screen is shown in

Box 1. The menu bar is relatively simple with just six options:

Menu headings	Function
File	For opening and saving files, running programs, printing, and setting options.
Edit	For cutting and pasting text and for undoing a mistake.
Search	For searching and replacing text within GAMS files.
Windows	For arranging the windows in different ways on the screen.
Utilities	For making macros, importing and exporting spreadsheets, and other tasks.
Help	For getting assistance in how to use GAMS

There are also seven buttons to carry out frequent tasks. In most cases, the buttons are just an alternative way of carrying out functions that the menu options. The buttons are :

Button	Function
Open folder	For opening files
Diskette	For saving files
Three flashlight buttons	For different types of searches
{a}	For checking to make sure parentheses are balanced
Printer	For printing a file
Red arrow	For running a GAMS program

Box 1. Screen after opening GAMS



When you first start on a new model, you will need to create a *project*, which tells GAMS where to find the files you will be working with. To create a project, click File/Project/New Project, select a folder, and type in the name of the project. The name can be anything that will help you remember what you are working on. When you create and name a project, GAMS puts a file with that name and extension prj in the folder you have chosen. This makes it easier to go back to this folder and find your files in the future.

Writing or editing a GAMS program

You can start writing a new GAMS program from scratch by clicking on File/New. A blank window will open and you can begin writing commands to compose a program. But you will probably never need to start writing a GAMS program from scratch. It is almost always easier to start with an existing program and modify it to meet your needs.

To open an existing GAMS program, click on File/Open and select the program file. For example, if you select "SD1 simple.gms", you will see a window appear with the GAMS program. Alternatively, from the Windows Explorer you can double-click on the file "SD1 simple.gms." Because Windows knows that the .gms extension is for a GAMS program, it will open GAMS and then open the program. In either case, you will see the program on the left side of the screen.

This program, “SD1 simple.gms,” is the simplest possible economic model, with the supply and demand for one commodity in one region. In spite of its simplicity, it has all the basic components of a GAMS program:

- First, the VARIABLE command gives names and labels to the two variables, quantity and price;
- Next, the EQUATIONS command names and labels the two equations (demand and supply) and then writes out the two equations (note that =E= is the equals sign);
- The MODEL command gives the model a name, “Market,” and lists the two equations that are in it;
- Finally, the SOLVE command tells GAMS which solver to use.

These four components are described in more detail at the end of this chapter.

The model is so simple that we can solve it without GAMS. The two equations are:

$$Q = 1800 - 2*P$$

$$Q = 1350 + P$$

This implies that:

$$1800 - 2*P = Q = 1350 + P$$

and, by adding 2*P to both sides and subtracting 1350 from both sides, we get:

$$450 = 3*P$$

so $P = 150$. Substituting this into the second equation above, we get $Q = 1500$.

In this case, we do not need GAMS to solve the problem. But economic models generally have dozen, hundreds, or even thousands of variables and equations. These problems clearly cannot be solved with a paper and pencil, but GAMS can solve them in a fraction of a second.

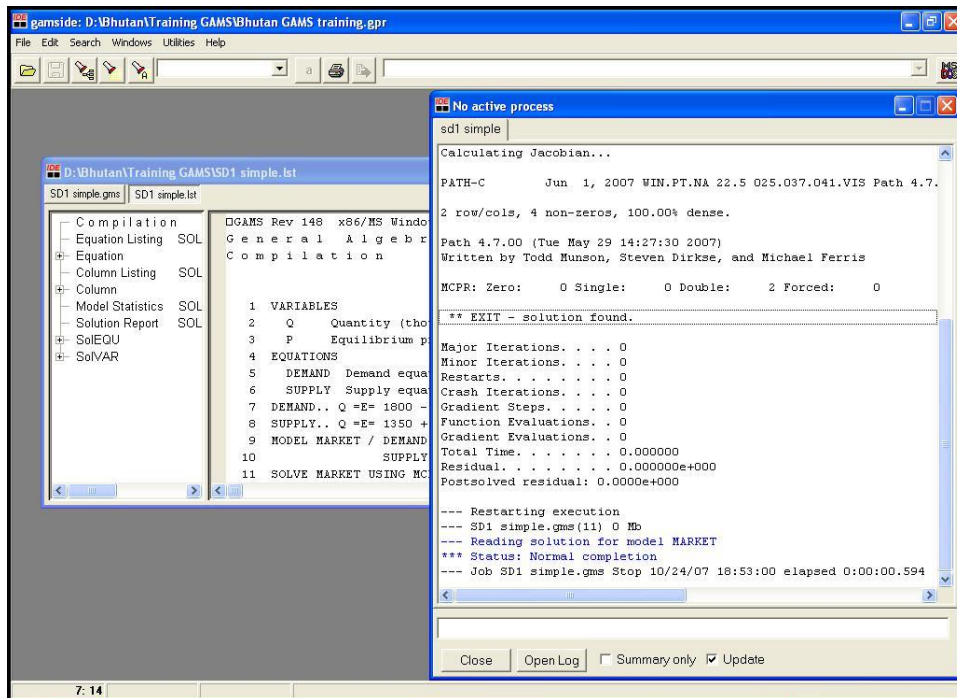
It is important to note that all GAMS programs, even very large complex ones, have the four components that are listed above: 1) a list of (endogenous) variables, 2) a list of equations, 3) a command to define the model, and a command to tell GAMS how to solve it. These commands are described in more detail below.

Running a program and reading the results

When we run a GAMS program, we are asking GAMS to read the program and solve the problem. To run a GAMS program, we click on the button with the red arrow. Almost instantly, GAMS will solve the model, create two files with output, and open windows to view each of these files, as shown in Box 2. The two windows are called the process window and the output window.

- The “process window” appears on the right side of the screen and shows you the .log file. This window provides information about the process of solving the model. Most importantly, it tells you if the program ran without errors or not.
- Also, the “output window” appears on the right side of the screen. It provides various results from running the program, including the solution. The output window is actually a tabbed window linked to the original program, so you can easily switch back and forth between the program and the output.

Box 2. Screen after running a GAMS program



If the program ran successfully, the process window will contain a statement in blue print saying “Status: Completion normal”. And the output window will show a lot of information, including the following:

- the GAMS program with numbered lines
- an “Equation Listing”
- a “Column Listing” with information about the variables
- some “Model Statistics” describing the size of the model, and
- the “Solve Summary” with the solution to the model

The most important section is in the Solve Summary where the variables are listed with four columns. The column labeled “Level” give the solution values for each variable.

If, on the other hand, the program has a problem, the process window will contain a statement in blue print saying “Status: Compilation error(s)” or some other type of error. In the output window, the place where GAMS found the errors in the program will be marked with “****” and an error code under the word in the command that may have caused the problem.

In the output window, you will find the entire program repeated, This is actually a new “tab” within the same window that showed the GAMS program. You can switch back and forth between the program and the output by clicking on the tabs at the top of the window.

Syntax for key GAMS commands

Now, we turn to a few of the most important GAMS commands: PARAMETERS, VARIABLES, EQUATIONS, MODEL, AND SOLVE. In the description of the format, the words in brackets (< >) describe what type of words should go in that place. The format shows groups of three but there may be more or less than three. There is also an example from the SDP4 in Annex 1.

PARAMETERS

This command defines the parameters used in the model. First, you list the names of the parameters with a short description. Then, you give the equations that define each parameter. The format is as follows:

PARAMETERS

```
<parameter name> <parameter description>
<parameter name> <parameter description>
<parameter name> <parameter description> ;

<parameter name> = <expression defining parameter> ;
<parameter name> = <expression defining parameter> ;
<parameter name> = <expression defining parameter> ;
```

An example from the SDP4.gms program (see Annex 1) is given below, along with the line numbers of each command (note that the line numbers were added to the text; they are not part of a GAMS program).

```
164  PARAMETERS
246      NER              Nominal exchange rate (1000 LC per US$)
247      POP (R)         Population in 1995 (inhabitants)

268      NER              = 11 ;
269      POP (R)         = POP94 (R) *1.0225 ;
```

VARIABLES

This command defines the variables used in the model. You list the variables with a short description of each.

VARIABLES

```
<variable name> <variable description>
<variable name> <variable description>
<variable name> <variable description> ;
```

An example from SDP4 is given below.

```
164  VARIABLES
165      P(C,R)          Equilibrium price (LC per kg)
166      D(C,R)          Quantity demanded (thousand tons)
167      S(C,R)          Quantity supplied (thousand tons) ;
```

EQUATIONS

This command defines the equations that describe the relationships among the variables and parameters in the model. Every equation has a name. First, you list the names of the equations with a brief description of each one. Then, you list the equations themselves. Notice that the equations use =E= to represent the equals sign.

EQUATIONS

```
<equation name> <equation description>
<equation name> <equation description>
<equation name> <equation description> ;
```

```

<equation name>..
    <variable name> =E= <expression> ;
<equation name>..
    <variable name> =E= <expression> ;
<equation name>..
    <variable name> =E= <expression> ;

```

Part of the EQUATIONS command from SDP4.gms (shown in Annex 1) is given below:

```

176 EQUATIONS
177 DEMAND Demand equation
178 SUPPLY Supply equation ;

186 DEMAND (C, R) . .
187 D (C, R) =E= DA (C, R) + DB (C, R) *P (C, R) + DC (C, R) *Y0 (R) ;
188
189 SUPPLY (C, R) . .
190 S (C, R) =E= SA (C, R) + SB (C, R) *P (C, R) ;

```

MODEL

This command names the model and the equations that are part of the model. Usually, all the equations listed are part of the model, but not always. The format is as follows:

```

MODEL <name of model> / <equation name>
                        <equation name>
                        <equation name> / ;

```

You can put two equation names on the same line, but they must be separated by a comma. The MODEL command in the model SDP4 (see Annex 1) is:

```

213 MODEL MARKET / DEMAND
214 SUPPLY
215 IN_OUT
216 DOM_TRADE.TQ
217 EXPORTS.X
218 IMPORTS.M
219 XQUOTA.IXT
220 MQUOTA.IMT / ;

```

SOLVE

This command tells GAMS the method to use to “solve” the model. “Solving” the model means finding the values of the variables that make all the equations true. The format is as follows:

```

SOLVE <name of model> USING <method> ;

```

The SOLVE command in the model SDP4 (see Annex 1) is given below.

```

221 SOLVE MARKET USING MCP ;

```

All the models in this course use the MCP method for solving models.

EXERCISE #2

This exercise uses a simple model with one equation (demand for rice) and one variable (the quantity of rice demanded). The price is fixed (exogenous). The exercise involves editing and running the program DEM1 and looking at the output.

1. Open GAMS, then open the GAMS program DEM1 by clicking on File/Open and then clicking on DEM1.
Notice that the program is divided into sections for the parameters, the variables, and the equations. In the parameter section, find the line that defines price.
What is the price of rice in this model?
Is price a parameter or a variable in this model?
Is quantity demanded a parameter or variable?
2. Run the model by clicking on the red arrow button.
Look at the output file on the left side of the screen (DEM1.LST)
Notice that the output file contains a numbered list of all the commands in the program file DEM1. It also contains a list of the parameters and variables. In the solution section, it gives information about each equation and each variable. Find the solution of the model by looking for VAR D
What is the quantity of rice demanded?
Exit the output file by typing ALT-F-X
3. Open the program DEM1 again by clicking on the tab for DEM1.gms.
Change the price of rice from 3000 LC/kg to 2500 LC/kg.
Run the model (same command as in Step 2).
Look at the output file (same command as in Step 2).
What is the new quantity demanded?
Why did the quantity demanded change? (circle a letter)
 - a) People decided they liked rice and wanted more.
 - b) The price rose so consumers decided to buy less.
 - c) The price fell so consumers could afford more.
 - d) The income of consumers rose so consumers could afford more.
4. Suppose we want to write a simple model to calculate the distance a car can go if it is traveling 53 kilometers per hour for 4.5 hours. The parameters are speed and time and the variable is distance. Open a new GAMS file and write a GAMS parameter command that defines the values of the two parameters (SPEED and TIME). Do not use line numbers.
5. In the same file, write a GAMS variable command for the distance variable. Give it the name DIST. Write a GAMS equation command to say that distance is equal to speed multiplied by time. Use the equation name SPEEDEQ.
6. Write a GAMS model command that says that SPEED is the name of the model and it contains the equation SPEEDEQ. Write the GAMS solve command so that the model SPEED is solved using MCP.
7. Now save the file calling it SPEED. Run the program SPEED. Look at the results in the file SPEED.LST. What is the distance traveled? Use a calculator to confirm that this is the correct answer.

SECTION 4: MODELING DEMAND

Key Words

Income and price coefficients, income and price elasticities, set, and index. GAMS commands SETS, PARAMETERS (with one index), * (for comments), INCLUDE, TABLES, and DISPLAY.

Economics of demand

In economics, “demand” refers to the amount that consumers are willing to purchase of a given product over a certain period of time. There are four main factors that affect consumer demand:

- the price of the product
- the price of related goods
- the income of consumers
- the preferences of consumers.

Not surprisingly, the higher the price of the product, the less consumers are willing to buy it. The relationship between price and demand is described by the own-*price elasticity of demand*, defined as the percentage change in the quantity demanded given a 1% increase in the price. Own-price elasticities of demand are almost always negative, often between -0.4 and -3.0. Products are classified according to their price elasticity:

Type of good	Range of price elasticity	Effect of price increase	Examples
Price inelastic	Between 0 and -1.0	Quantity consumed declines, but total spending on product rises	Staple foods, salt, products with few substitutes
Price elastic	More negative than -1.0	Quantity consumed and total spending on the product declines	Luxury foods, products with many substitutes

The demand for a certain product is also affected by the price of related products. For example, if the price of rice rises, consumers may shift to wheat or maize so the demand for these commodities rises. Similarly, if the price of apples rises, the demand for oranges may increase. Two products are called *substitutes in consumption* if an increase in the price of one causes an increase in the demand for the other.

Alternatively, an increase in the price of one product may cause a *decrease* in the demand for a related product, particularly if the two are normally consumed together. For example, an increase in the price of hamburgers would probably cause a reduction in the demand for hamburger rolls. Similarly, a large increase in the price of petrol might cause a reduction in the demand for cars. Two products are called complements in consumption if an increase in the price of one causes a decrease in the demand for the other.

The relationship between the price of one product and the demand for a different product is described by the *cross-price elasticity of demand*. Generally, cross-price elasticities of demand are much smaller than

own-price elasticities of demand.

The demand for a product is also affected by the income of consumers. This relationship is described by the income elasticity of demand, defined as the percentage increase in demand for a good when income rises by 1 percent. When income rises, the demand for most products rises, although the demand for some products may fall. For most products, the income elasticity is between 0.0 and 2.0. Products are classified according to the size of the income elasticity.

Type of good	Range of income elasticity	Effect of income increase	Examples
Inferior	Negative	Quantity consumed and share of budget allocated to this product declines	Less desirable staple foods (e.g. cassava?)
Normal	Between 0.0 and 1.0	Quantity consumed increases, but share of the budget allocated to this product declines	Most food, with staple food elasticities being lower than fruits and vegetables
Superior	Greater than 1.0	Quantity consumed and share of the budget allocated to this product increases	Some high-value foods like meat and food consumed outside the household and many non-food products like housing and leisure services.

The demand for a product is also affected by preferences and tastes. Even if prices and income are the same, two households may differ in their demand due to different preferences, perhaps related to religion, culture, education, family background, or individual experiences. For example, the demand for pork is much less in countries with a large Muslim population. Similarly, in India, the demand for meat is lower and the demand for dairy products is higher than in other countries with similar prices and income.

Simulating demand using GAMS

When simulating the demand for a product by large groups of people, we normally limit the factors to price and income. For example, a demand equation might be:

$$\text{demand} = 7500 - 2 * \text{price} + 3 * \text{income}$$

In this equation and in GAMS, the asterisk (*) indicates multiplication. The demand intercept is 7500, the price coefficient is 2, and the income coefficient is 3. The income coefficient determines how changes in income affect demand. In this example, if the income rises by 100, demand rises by 300. For a *normal good*, a higher income increases demand, so the income coefficient is positive. For an *inferior good*, a higher income reduces demand, so the income coefficient is negative.

Often, we want to represent more than one market in GAMS. For example, we may want to create a model

that represents the market for rice in more than one region, such as north and south. Or we may want a model that represents more than one product, such as rice and maize. Or we may need to represent more than one region *and* more than one product in the same model.

One way to represent more than one market is to create separate variables, parameters, and equations. For example, suppose we want to represent the demand for rice in the north and south of A country. We could write a model like this:

```
PARAMETERS
  AN  Intercept in the north
  AS  Intercept in the south
  BN  Price coefficient in the north
  BS  Price coefficient in the south
  PNOR Price in the north
  PSOU Price in the south ;
  AN  = 7500 ;
  AS  = 9500 ;
  BN  = -1 ;
  BS  = -2 ;
  PNOR = 3500 ;
  PSOU = 2000 ;

VARIABLES
  DNOR Demand for rice in the north
  DSOU Demand for rice in the south

EQUATIONS
  DEMANDN Demand in the north
  DEMANDS Demand in the south ;
DEMANDN..
  DNOR =E= AN + BN*PNOR ;
DEMANDS..
  DSOU =E= AS + BS*PSOU ;
```

However, It is more convenient to write this model using *sets* and *indexes*, as follows:

```
SETS
  R      Region      /North
                        South /;

PARAMETERS
  A(R)  Intercept of demand function
        /North 7500
        South 9500 /
  B(R)  Price coefficient of demand function
        /North -1
        South -2 /
  P(R)  Fixed price (LC per kg)
        /North 3500
        South 2000/

VARIABLES
  D(R)  Quantity demanded (thousand tons) ;

EQUATIONS
  DEMAND Demand equation ;
DEMAND(R) ..
  D(R) =E= A(R) + B(R)*P(R) + C(R)*Y(R) ;
```

The SET command defines the set of regions (North and South) and a variable to represent regions (R). On paper, indexes are often written as subscripts, so that P_R might refer to the regional price, P_{North} might be the price in the north, and P_{South} is the price in the south. Since not all computers can write subscripts, GAMS uses parentheses instead of subscripts. In this example, $P(R)$ would refer to the regional price in general,

while P('North') and P('South') would refer to the prices in the north and south, respectively. Note that when the index refers to a specific element on the set, it must be in single quotation marks ('xxx').

The model still has two equations: one for the north and one for the south. However, now it is written in the GAMS program as one command. We say there is one *block* of equations and two equations. Similarly, the model SDP4 has 8 blocks of equations, but 248 equations.

SETS

The SETS command is used to define sets of parameters and variables to simplify the presentation of the equations. The general format is as follows:

```
SETS <name of set> <label for set> /   <1st item> <1st label>
                                         <2d item> <2d label>
                                         <3d item> <3d label> /
```

An example from the SDP4 model is as follows:

```
12 SET
13   C           Crops /Rice
14               Maize
15               Mustard
16               Citrus /
17  RW          Region including world
18               /WEST
19               CENTRAL
20               EAST
21               S_WEST
22               S_CENT
23               S_EAST
24               WORLD /
25  R(RW)       Region
26               /WEST
27               CENTRAL
28               EAST
29               S_WEST
30               S_CENT
31               S_EAST /;
```

PARAMETERS (with one index)

We have already discussed the PARAMETER command, but the format is different when we have parameters with indexes. If a parameter has just one index, such as A(R), then the PARAMETERS command can list the values of the parameter as follows:

```
PARAMETERS
  <parameter name with index>   <parameter description>
  / <#1 in index>               <value>
    <#2 in index>               <value>
    <#3 in index>               <value> /;
```

The list may have any number of elements (not just three as above). The SDP4 model does not use this command, but below is an example of the use of the PARAMETER command to give the population for each

region:

```
PARAMETERS
  POP (R)      Population
                /WEST      150000
                CENTRAL    100000
                EAST       95000
                S_WEST     120000
                S_CENT     98000
                S_EAST     72000 /;
```

In this example, WEST through S_EAST are elements in the set of regions that is named R. The semi-colon must go at the end of the last list, not after each list.

If a parameter is defined by an equation, then the format for the command is the same with or without an index. This is shown in the following example from the SDP4 model. The import and export price in LC for each commodity (index C) are defined in terms of the world price in dollars, the exchange rate, and the tax.

```
529  PARAMETERS
530
531  PM(C)      Import price after tariffs (D per kg)
532  PX(C)      Export price after taxes (D per kg)
538
539  PM(C)      = PW(C, 'M') *NER*(1+TAX(C, 'M')) ;
540  PX(C)      = PW(C, 'X') *NER*(1-TAX(C, 'X')) ;
```

***(for comments)**

Sometimes it is useful to include text in a program that does not run any command. There are several reasons for this: 1) it is useful to explain what each section is designed to do, 2) it is a good idea to give the source of data found in a program, and 3) you may want to “turn off” some commands without erasing them. If you put an asterisk (*) in the first column of a line, GAMS will ignore that line. In the following example, lines 227 and 228 are ignored by GAMS.:

```
222  MARGWR(C)  Wholesale-retail margin (D per kg)
223                / RICE      204
224                MAIZE      138
225                SWPOT      93
226                MANIOC     44 /
227  * Source: MARD, avg difference between wholesale and retail prices
228  *           for 21 districts, avg over 12 months in 1995.
```

Notice that you must put an asterisk at the beginning of *each* line that is part of the comment.

Until now, all the equations we have used have been *linear*. In other words, they all have had the form:

$$D = a + bX_1 + cX_2 + dX_3$$

However, it is not necessary to use linear equations. GAMS can solve models with *non-linear* equations also. As discussed earlier in this module, one of the more common types of demand equations is the Almost Ideal Demand System (AIDS). In this demand equation, the budget share (s) is a function of the log of prices (p) and the log of real income (Y/P).

$$s_i = D_i p_i / Y = a_i + b_i \log(p_i) + c \log(Y/P)$$

This equation is more flexible than the linear equation in representing demand. In this section, we will show

how the AIDS demand equation can be represented in GAMS. The AIDS equation normally has the prices of various goods in it, so that the demand for a good is affected by its own price and the prices of related goods. The impact of changes in the prices of other goods is called cross-price effects. In this module, however, we use a simple version of the AIDS in which the demand for each good is only affected by its own price.

Demand for multiple goods in multiple markets

Until now, all the examples we have looked at have had just one product. However, GAMS can solve models that have more than one region *and* more than one product. For example, the SDP4 model has six regions and four commodities.

In order to have multiple products and multiple regions, some variables such as demand need two indexes: one for the region and one for the product. Demand is represented by $D(C,R)$, where C represents the commodity and R the region. In addition, some parameters such as price need two indexes. Price is represented by $P(C,R)$. In this module, we show how to write models with two indexes in GAMS, and we introduce some new GAMS commands.

TABLE

The TABLE command is used to define parameters with more than one index. The values are described in a table with the different values of the indexes in the first row and in the first column.

```
TABLE <parameter name with indexes>      <parameter description>
                                     <#1 in index 2> <#2 in index 2> <#3 in index 2>
<#1 in index 1>      <value>          <value>          <value>
<#2 in index 1>      <value>          <value>          <value>
<#3 in index 1>      <value>          <value>          <value> ;
```

An example from SDP4 is as follows:

```
35 TABLE P0(C,R) Original price (LD per kg)
36
37      WEST  CENTRAL  EAST      S_WEST  S_CENT  S_EAST
38 RICE      2987      2982      2756    2636    2354    2368
39 MAIZE      2112      1988      1882    1439    1321    1694
40 MUSTARD   1553      1372      1003    1245     731     731
41 Citrus     535       473       499     584     486     486 ;
```

Note that the first index (C for the crop) identifies the different rows in the table, while the second index (R for region) identifies the different columns.

When a parameter is defined by an equation, then the format for the command is the same with or without an index. This is shown in the following example from the SDP4.

```
138 DB(C,R)          Price coefficient of demand equation
155 DB(C,R) = DPE(C,R)*D0(C,R)/P0(C,R) ;
```

INCLUDE

The INCLUDE command is used to insert the commands from one program file into another program file. This is useful for dividing a long program into several modules that can be tested and modified separately. The format is as follows:

```
$INCLUDE "<name of file>" ;
```

Note that the \$ must be in the first column. When GAMS comes to this command, it goes to the other program file and runs all the commands in that file, then returns to run the commands after the INCLUDE command in the original program file.

For example, in the model DEM5, the following command appears:

```
$INCLUDE "DEM5a" ;
```

At this point in the program, GAMS runs the commands in the file DEM5a before continuing with the commands in DEM5 after the INCLUDE command.

DISPLAY

The DISPLAY command is used to specify the type of output generated by the GAMS program. This command can be used to show the values of parameters and variables. In the case of variables, you must attach .L to the end of the variable name. The L stands for level. The general format is as follows:

```
DISPLAY <parameter name>, <parameter name>, <variable name>.L, <variable name>.L ;
```

This command will print any number of parameters and variables in any order. The list can continue over various lines.

```
1046 DISPLAY CALIB3, PD0, PD.L, PS0, PS.L, PW, S0, S.L, D0,  
1047         BS0, BS.L, NFYPC0, YPC0, YPC.L, FOODPCT,  
1048         DYE, DPE2, SPE, SBETA, TP, ITX, MARGD, MARGX, MARGM ;
```

PD0 is a parameter so it does not need an L, while PD is a variable so it does need an L.

Exercises for Section 4

DEM2 is a model of two markets, each of which has a fixed price. It has two demand equations and two variables. The SETS command defines the index R (region) and its two values N (North) and S (South). The index allows the same type of equation to describe demand in different regions or for different products.

1. Enter the file DEM2.
Notice that every parameter has a north and south value.
What is the price in the north?
What is the price in the south?
Exit the program.

2. Run the program by typing GAMS DEM2
Open the output file (DEM2.LST)
What is the quantity consumed in the north?
What is the quantity consumed in the south?
Exit the output file.
3. Enter the program DEM2
Change the price in the south to 3000 LC/kg
Exit and run the program.
Look at the output file.
What is the new quantity consumed in the north?
What is the new quantity consumed in the south?
Why did the the quantity change in the south?
 - a) Income increased so consumption increased.
 - b) The price fell so consumption increased.
 - c) The price rose so consumption decreased.
 - d) Consumer preferences changed so consumption decreased.
4. Suppose income in the north rose from 1.5 to 2.0 million LC per capita. Open the file DEM2 and change the income parameter in DEM2 to reflect this new situation. Now exit DEM2 and run it.
Look at the output file (DEM2.LST).
What is the quantity consumed in the north?
What is the quantity consumed in the south?
Why did the quantity consumed change in the north?

DEM3 is a model of demand for two goods in two regions with fixed prices. It uses linear demand equations with income terms. The TABLE command is used to give the values of parameters with two indexes.

Notice that the income coefficient is now called GAMMA instead of C. This is because we have called the commodity index C and GAMS does not allow an index and a variable to have the same name.

1. Open the file DEM3 and look at the parameter section.
What is the demand intercept for rice in the north?
What is the price coefficient for rice in the south?
What is the income coefficient for maize in the south?
2. Why does the income parameter have just one index?
 - a) This is a mistake, it should have two indexes.
 - b) Because income is a parameter, not a variable.
 - c) Because income varies by region, but not by product.
 - d) Because the model would be too complicated if it had two.
3. Run the program DEM3 and look at the results.
What is the demand for rice in the north?
What is the demand for rice in the south?
What is the demand for maize in the south?
What is the demand for maize in the north?
4. Open the program file again. Increase the income in both north and south by 500. Run the model and look at the results.

What is the demand for rice in the north?

What is the demand for maize in the south?

Which of these two increased more?

- a) rice demand in the north
- b) maize demand in the south

Why did it increase more than the other?

- a) Maize is not an important food in The country.
- b) The income coefficient of rice demand in the north is higher.
- c) The supply of maize is more limited.

SECTION 5: MODELING SUPPLY

Key Words

Price coefficient, supply elasticity, log-linear equation, own-price elasticity, cross-price elasticity of supply, substitutes in production, and symmetry. GAMS commands PARAMETER with more than one index, commands to set initial values, commands to produce output tables, ALIAS, SUM, and TABLE with three indexes.

Economics of supply

Supply equations are used to represent the response of producers of a product to changes in the price of the product and other factors. If the price of a product increases, the producers are likely to increase output by switching resources to the production of that good or by using more resources. In agriculture, resources include land, labor, fertilizer, and water. A farmer may respond to higher rice prices by switching land from maize production to rice production. The farmer may also increase the total amount of land or apply fertilizer more intensively than before. In any case, the level of rice production will generally rise following an increase in the price of rice.

The supply response is measured using the *price elasticity of supply*, defined as the percentage change in output in response to a one percent change in price. Supply elasticities in agriculture are generally between 0 and 2, with a majority of the estimates being between 0 and 1. Various factors affect the size of these supply elasticities:

Length of time: In the very short run (less than 3 months), supply elasticities are close zero because it takes time for farmer decisions to affect output.

Type of crop: In the medium term (1-3 years), annual crops such as rice and maize have higher supply elasticities than tree crops such as coffee, tea, and rubber. This is due to the delay between the planting of new tree crops and the increase in supply.

Cropping intensity: Crops that are planted and harvested more than once per year will respond to price changes more quickly than crops that are planted and harvested annually.

Existence of substitutes in production: If a crop competes closely with other crops (eg maize), its supply will be more sensitive to price. Crops that are grown on land that is not useful for other crops (eg cassava) tend to be sensitive to changes in price.

Type of technology: Crops that are grown with modern technology, including fertilizer and other chemical inputs, tend to be more price elastic because farmers can adjust the yield depending on price.

Simulating supply using GAMS

The simplest supply equation is a linear relationship between the level of output and the price:

$$S = a + b \cdot p$$

In a linear supply equation, the supply elasticity is different at every point. Normally, the elasticity is calculated at the current level of supply (S_0) and the current price (p_0) using the following formula:

$$\text{supply elasticity} = e_{ii} = b \cdot (p_0/S_0)$$

A somewhat more complicated supply equation is the double-log function. This equation can be expressed as follows:

$$\log(S) = a + b \cdot \log(p)$$

One advantage of this equation is that the price coefficient (b) is the supply elasticity. In other words:

$$\text{supply elasticity} = e_{ii} = b$$

Supply equations often include terms to reflect the effect of *other* prices on supply.

Problems related to logarithms

The logarithm of x is the power to which e (a number approximately equal to 2.7) needs to be raised to get x . In other words, $e^{\log(x)} = x$. One peculiarity of logarithms is that the logarithm (or “log”) of zero or a negative number is not defined. GAMS will give an error message and stop the run if it comes to a step involving the log of a negative number.

Normally this would not be a problem since neither S (supply) nor p (price) in the supply equation are zero or negative. However, GAMS solves models by doing a complex “search” of possible values of the endogenous variables. It starts this search by setting the variable(s) to zero. This starting point generates an error message in GAMS. The solution to this problem is simple: we need to tell GAMS to start the search with a positive number. For example, the format of this command is as follows:

```
<variable name>.L = 1 ;
```

The SDP4 does not need to set initial values, but here are some examples from another model. These commands serve to avoid the error message and they also “help” GAMS find the solution by providing a starting point for the search. The starting points are the values of the variables in the base scenario, indicated by the ‘0’ at the end of the name.

```
612 * INITIAL VALUES
613
614 * General initial values
615 PD.L(C,R) = PD0(C,R) ;
616 PS.L(C,R) = PD0(C,R) -MARGD(C,R,R) ;
617 BS.L(C,R) = 100*BS0(C,R) ;
618 S.L(C,R) = S0(C,R) ;
619 PINDEX.L(R) = 1 ;
```

Creating output tables

GAMS automatically produces a results file with the values of the endogenous variables. Sometimes, it is useful to present the results in a different way or to design tables which summarize the most important results.

In addition, it may be useful to compare the results with another simulation, such as the base scenario. This can be done by combining PARAMETER and DISPLAY commands after the SOLVE command. In order to use the value of the endogenous variables from the solution, we must add .L to the variable name. For example, in order to use the value of S (supply), we use S.L to indicate the *level* of S in the solution.

SUP3 provides a simple example. The two new parameters are defined as the percentage change in price and supply compared to their original values, P0 and S0. Note that the endogenous variable S (supply) is in the equation as S.L(C,R). The two OPTION commands tell GAMS to print only one digit at the right of the decimal point (5.1 instead of 5.138943).

```
PARAMETERS
  PCCPRICE(C,R)   Percentage change in price
  PCCSUPPL(C,R)   Percentage change in supply ;
  PCCPRICE(C,R)   = 100*(P(C,R)-P0(C,R))/P0(C,R) ;
  PCCSUPPL(C,R)   = 100*(S.L(C,R)-S0(C,R))/S0(C,R) ;

OPTION PCCPRICE:1 ;
OPTION PCCSUPPL:1 ;
DISPLAY PCCPRICE, PCCSUPPL ;
```

The following is a somewhat more complicated example. The asterisk (*) in the parameter definition indicates that the values of the third index will be defined later. In the parameter equations, the values of the third index are specified by the words in quotation marks. Note that the variables (S and X) are followed by ".L" but the parameters are not.

```
PARAMETERS

TAB5(C,R,*)      Regional volumes (1000 tons)

TAB5(C,R,'Demand') = D(C,R) ;
TAB5(C,R,'Supply') = S.L(C,R) ;
TAB5(C,R,'Surplus') = S.L(C,R)-D(C,R) ;
TAB5(C,R,'Exports') = X.L(C,R) ;
TAB5(C,R,'Imports') = M.L(C,R) ;
DISPLAY TAB1, TAB2, TAB2PCT
          TAB3, TAB3PCT ;
DISPLAY TAB4, TAB5, TAB6, IXT.L ;
```

PARAMETERS with more than one index

In Section 4, we explained how the TABLE command can be used to provide the values of parameters with two or more indexes. The PARAMETER command can also be used to list the values of a parameter with two or more indexes. In this case, the values of the indexes are listed to the left of the data. This is an example from SDP4 (see Annex 1):

```
118  TABLE ITX(C,R,RR)      Implicit tax on internal trade (LC per kg)
119
120          WEST      EAST      S_WEST  S_CENT  S_EAST
121  RICE  .WEST                400      400
122  RICE  .EAST                200
123  RICE  .S_WEST              100      100
124  RICE  .S_CENT              400      200      100
125  RICE  .S_EAST              400                100
126  MAIZE .WEST                300      300
127  MAIZE .S_CENT              300
```

```

128 MAIZE .S_EAST      300
129 MUSTARD .WEST      300      300
130 MUSTARD .S_CENT    300
131 MUSTARD .S_EAST    300
132 CITRUS.WEST      300      300
133 CITRUS.S_CENT     300
134 CITRUS.S_EAST     300      ;

```

The first index (C for crop) is in the first column, the second index (RW for region) is in the second, and the third index (RWW for region) in the third column. Thus, the implicit tax on rice between the MRD and the Central Highlands is 100 (see line 176). Note that the columns of index values must be separated by a dot (.). The difference between a TABLE command and a PARAMETER command is that the TABLE command has at least two columns of data, while the PARAMETER command can have no more than one column.

Cross-price supply effects

The supply equations discussed in Section 5 assume that supply is a function of the price of the same product only. In fact, supply of a commodity is affected by the prices of related goods. For example, the supply of maize is affected by the price of rice. When the supply of two goods is affected by the price of the other good, we say they are *substitutes in production*. Usually, this is because producers can switch between the two goods depending on the profitability of each. Because farmland can be changed from one crop to another, many crops are substitutes in production. In general, the effect of the price of one good on the supply of other goods is called a *cross-price effect*. In contrast, the effect of a price on the supply of the same good is called the *own-price effect*.

We represent cross-price effects by including other prices in the supply equation. In the linear model, the result would be as follows:

$$S_i = a_i + b_{ii} p_i + b_{ij} p_j + b_{ik} p_k \dots = a_i + \sum b_{ij} p_j$$

In the log-log model, we include cross-price effects as follows:

$$\log(S_i) = a_i + b_{ii} \log(p_i) + b_{ij} \log(p_j) + b_{ik} \log(p_k) \dots = a_i + \sum b_{ij} \log(p_j)$$

Note the price coefficient now has two indexes: one representing the crop affected and the other representing the crop whose price is affecting the other. In other words, b_{ij} represents the effect of p_j on S_i . Because both indexes represent crops, we need two different indexes that represent crops. If we add a regional index, the price coefficients have three indexes. Below, we show how the values of a parameter with three indexes can be organized in a TABLE command.

ALIAS

In general, an “alias” is a second name for the same person or thing. In GAMS, an alias is a second name for the same index. The format is to put the two aliases in parentheses after the ALIAS command. Commas separate the two aliases and the different pairs of aliases. The SDP4 program has two indexes with aliases, as shown:

```
32  
33 ALIAS (R,RR) , (RW, RRW) ;  
34
```

The usefulness of this command will be easier to see when we discuss the GAMS equations used to represent cross-price effects.

SUM

SUM is not a command in GAMS, but rather a function which can be used in equations. The SUM function in GAMS is equivalent to the summation sign (\sum) in conventional math notation. The general format of the SUM function is as follows:

SUM(<index>, <expression>)

An example of the SUM function in the SDP4 model is as follows:

```
192     IN_OUT(C,R) ..
193     S(C,R) + SUM(RR,TQ(C,RR,R)) - SUM(RR,TQ(C,R,RR)) - X(C,R) + M(C,R)
194     =E= D(C,R) ;
```

This equation says that supply of a given commodity in one region plus inflows from all other regions minus outflows to all other regions minus exports plus imports is equal to demand.

The SUM function can also be used for summation over two or more indexes, by putting the indexes in parentheses. For example, the total value of all crops in the model over all the regions in the model (VALPROD) can be written as:

```
VALPROD = SUM((C,R), S(C,R)*P(C,R)) ;
```

In mathematical notation, this would be written as:

$$\text{VALPROD} = \sum_C \sum_R S_{CR} P_{CR}$$

As mentioned above, when you sum over one or more indexes (C and R in this example), those indexes cannot appear in the result (VALPROD in this example). Thus, VALPROD does not have any indexes because it is a sum over all regions and over all crops in the model.

TABLE with more than two indexes

In Module 2, we discussed the TABLE command which presents the values of parameters in a table-like format. The examples we used all had two indexes. However, the TABLE command can also be used to give the values of parameters with three (or more) indexes. This is done by having two (or more) indexes in columns to the left side of the table and the last index indicating the column. The two columns of index values are separated by dots (.), as shown in this example from the model SDP4 (see Annex 1):

```
118     TABLE ITX(C,R,RR)      Implicit tax on internal trade (LC per kg)
119
120           WEST      EAST      S_WEST  S_CENT  S_EAST
121     RICE  .WEST                400      400
122     RICE  .EAST                200
123     RICE  .S_WEST              100      100
124     RICE  .S_CENT      400      200      100
...
```

The format of these columns of index values is identical to the columns in the PARAMETER command when there are two or more indexes. As mentioned above, the key difference between the PARAMETER command and the TABLE command is that the former can have no more than one column of data, while the latter can have no less than two.

Exercise #4

Open the program file SUP1 and answer the following questions about the program.

1. Is the model in SUP1 linear or double-log?
2. Which best describes the model?
 - a) a 2-crop, 2-region model
 - b) a 2-crop, 1-region model
 - c) a 1-crop, 2-region model
 - d) a 1-crop, 1-region model
3. Run three simulations with the price at the different levels in this table and write the quantity supplied for each simulation.

Price (D/kg)	Quantity supplied (1000 t)
1500	
3000	
4500	

4. Make a graph (by hand) with price on the vertical axis to show the three points that correspond to the simulation.
5. In terms of the parameters in the model, why does the line go “upward”?
6. In terms of economic logic, why should the line go “upward”?
7. Calculate the elasticity of supply at the original point ($p = 3000$). Remember that the elasticity from a linear equation is calculated as:

$$E_i = b (p/S)$$

Open the program file SUP3 and answer the following questions.

8. Add commands at the end of the program so that it calculates and displays the *value* of crop production *for each crop and each region*. Call the parameter VALRC.
9. Add commands at the end of the program to calculate and display the *national* value of each of the two crops. Call the parameter CROPTOT.
10. Add commands at the end of the program to calculate and display the value of the production of *both crops for each region*. Call the parameter REGTOT.

SECTION 6: EQUILIBRIUM FOR NON-TRADABLE GOODS

Key words

Equilibrium price, equilibrium quantity, commodity balance, change in quantity demanded vs shift in demand curve, change in quantity supplied vs shift in supply, and static comparative analysis.

Economics of market equilibrium

In the previous modules, we considered supply and demand separately with an exogenous price. However, it is not realistic to consider price to be exogenous except when the government sets the price. In a market economy, prices are determined by the interaction between supply and demand. For example, if the weather is good and the rice harvest is larger than usual, the increase in supply causes prices to fall. Another example is that during Tet, people increase the demand for some goods and this can cause some prices to rise. In other words, in a market economy, prices are not exogenous - they are endogenous.

In the market, the *equilibrium price* is the price which makes the quantity supplied equal the quantity demanded. This quantity is called the *equilibrium quantity*. If the price is below the equilibrium price, supply will be less than demand. Some consumers will not be able to buy all they want to buy and this demand will push the market price higher. On the other hand, if the price is above the equilibrium price, demand will be less than supply. Producers will not be able to sell all they want to sell at this price, so they will offer discounts which push the price down. Thus, there is a natural tendency to move toward the equilibrium price.

Although prices tend to move toward their equilibrium level, they do not move their instantly. There are often delays in responding to new prices, partly because of lack of good information and partly because producers and consumers cannot react instantly to conditions. In many types of economic analysis, we compare two equilibriums without trying to show the process of adjustment from one equilibrium to the other. For example, we might compare the equilibrium prices and quantities under a 10% rice export tax with the equilibrium prices and quantity under a 3 million ton rice export quota. This is called *static comparative analysis*.

Representing a market equilibrium in GAMS

In any economic model, the number of equations must be equal to the number of endogenous variables. We have already said that in a market economy, prices are endogenous. Thus, we have three types of endogenous variables:

quantity supplied (S)
quantity demanded (D)
equilibrium price (P)

To solve the model, we need three equations. We have already worked with the demand equation and the supply equation. The third equation is the *commodity balance*. In a simple model without trade, the commodity balance says that supply equals demand ($S = D$). Thus, the three types of equations are:

$$S = f(P)$$

$$D = g(P, Y)$$

$$S = D$$

Using simple linear models of supply and demand, the model would look like this:

$$S = sa + sb * P$$

$$D = da + db * P + dc * y$$

$$S = D$$

where S, D, and P are endogenous variables and sa, sb, da, db, dc, and y are exogenous variables (or “parameters” in GAMS).

If the model has many goods and many regions, we can still solve the model. Suppose there are C goods and R regions. Then the number of endogenous variables will be 3*C*R (C*R supply variables + C*R demand variables + C*R prices). But there will also be 3*C*R equations (C*R supply equations, C*R demand equations, and C*R price equations). Thus, the equality of equations and endogenous variables still holds.

In analyzing the movement of prices and quantities, it is important to distinguish between changes in quantities and shifts in the supply and demand curve. A *change in the quantity demanded* refers to movement along the demand curve, while a *shift in demand* refers to movement of the demand curve itself. Similarly, a *change in the quantity supplied* refers to movement along the supply curve, while a *shift in supply* refers to movement of the supply curve itself. For example, if income rises the demand curve will shift to the right (an increase in demand). The equilibrium price, the quantity demanded, and the quantity supplied will increase. This is *not* the same as an increase in supply.

Excercise #5

1. Open the file SD1. Look at the three variables and the three equations. Run the model and look at the results.
What is the equilibrium quantity supplied?
What is the equilibrium quantity demanded?
What is the equilibrium price?

2. Calculate the following elasticities at the equilibrium:
income elasticity of demand
price elasticity of demand
price elasticity of supply

11. Suppose that a drought reduces the harvest by 2 million tons. We can represent this by reducing the supply intercept by 2000. Run the model and look at the results.
What is the equilibrium quantity supplied?
What is the equilibrium quantity demanded?
What is the equilibrium price?

Answer true or false:

- Supply decreased
- Quantity supplied decreased
- Demand decreased
- Quantity supplied decreased

12. Suppose income increases by 10%. Change the income parameter to show this. Run the model and look at the results.

What is the equilibrium quantity supplied?
What is the equilibrium quantity demanded?
What is the equilibrium price?

Answer true or false:

- Demand increased
- Quantity demanded increased
- Supply increased
- Quantity supplied increased

SECTION 7: INTERNATIONAL TRADE

Key words

World prices, CIF price, FOB price, export parity price, import parity price, autarky price, export price relations, import price relations, commodity balance, small country assumption, large country assumption, complementarity relationship, export tax, import tax (or tariff), export quota, import quota, implicit export tax, implicit import tax, binding quota, economic rent, exchange rate, appreciation, depreciation, and purchasing power parity. GAMS commands POSITIVE VARIABLE and requirements for inequalities.

Economics of international trade

The economic principles of trade between two regions of one country are no different than the principles of trade between a country and the rest of the world. In practice, however, there are some differences:

- International trade is subject to a wide variety of policy interventions such as import tariffs, export taxes, import quotas, export quotas, local-content rules, and so on. Taxes and restrictions on trade between regions are typically small.
- The transportation costs of international trade are often larger than the costs of internal trade, although this is not always true.
- Different regions of a country are usually of similar sizes. Thus, changes in supply or demand in one region affect prices in other regions. In contrast, changes in supply or demand of one country have little or no effect on world trade because each country's trade is small relative to world markets.

We begin by assuming there are no policy barriers to international trade to focus on the relationship between world prices, transportation costs, and domestic prices. Later in Section 7, we consider the effect of taxes and quotas on imports and exports.

The analysis of international trade policy is simpler if we assume that the country's policies have no effect on international prices. This is called the small country assumption. The small country assumption is reasonable for a country when the country's exports and imports are a small proportion of world trade. What is a "small" proportion? The small country assumption is probably reasonable provided that the country does not account for more than 10-20 percent of world trade in each commodity.

The large country assumption is that exports or imports from the country are large enough to affect world markets. Imports are relatively evenly distributed among countries, so each country's share of import markets is normally small. As a result, only very rarely are countries able to affect the prices of goods they import. Exports, on the other hand, tend to be more concentrated, so large countries are less rare. Brazil is a "large" country in the world coffee market, and Thailand is a "large" country in the world rice markets.

Throughout Section 7, we adopt the small country assumption. In the next section, we discuss how to model trade between regions, which involves techniques that can also be used to model trade under the large country assumption.

Export and import prices

Export and import prices differ because of transportation costs. The cost of importing a good would be the world price plus the cost of transportation, handling, insurance, etc. to the country. If the world price of maize is \$ 200 per ton and transportation costs are \$ 50 per ton, then the long-run equilibrium import price in the country would be \$ 250 per ton (assuming competitive markets). This is called the *CIF price* (CIF means cargo, insurance, and freight).

If maize were exported from the country, the domestic price would be the world price minus the cost of transporting it there. Thus, the export price in the country would be $\$ 200 - \$ 50 = \$ 150$. This price is called the *FOB price* (FOB means free on board). The gap between the import price (\$ 250) and the export price (\$ 150) is twice the transportation cost.

If there are no trade restrictions, the CIF and FOB prices put an upper and a lower limit on price in the port city of the country. Why is this? If the domestic price of maize rises above \$ 250, traders will import more maize and push the price down to \$ 250 per ton. No one in the country would buy maize at \$ 260 per ton if they could import it at \$ 250 per ton. Thus, \$ 250 is the upper limit of maize prices in the country.

At the same time, if the domestic price of maize falls below \$ 150 per ton, traders will export maize, pushing the local price up. No one would sell maize in the country for \$ 140 if they could export it for \$ 150 per ton. Thus, \$ 150 is the lower limit on the long-run maize prices in the country.

International prices also put upper and lower limits on the prices in the interior of the country, but the gap is wider because of the transportation costs within the country. Suppose it costs \$ 15 per ton to transport maize from the port city to an interior city. Then maize prices in the interior city cannot rise above \$ 265. This is called the *import parity price* (the cost of importing maize and transporting it there). Nor can maize prices in the interior city fall below \$ 135 per ton. This is called the *export parity price* (the FOB price minus the cost of transporting to the port).

Direction of trade

How do we know whether the country will import or export a given product? It depends on the *autarky price*, defined as the price that would occur in the absence of international trade. The direction of trade (importing or exporting) depends on the relationship between the autarky price, the import parity price, and the export parity price. The table below describes this relationship.

If the autarky price is:	then the country will:	and the domestic price will settle at:
Above the import parity price	import the commodity	the import parity price
Between the import and export parity price	neither export nor import the commodity	the autarky price, between the import parity price and the export parity price
Below the export parity price	export the commodity	the export parity price

Of course, these rules apply only when there are no restrictions in international trade within the country and competitive markets. The effect of policy restrictions will be later in this Section.

Exchange rates

Until now, we have expressed all prices in US dollars. The same rules could be expressed in terms of local currency (LC) by multiplying the US dollar values by the exchange rate in LC per US dollar. It is very important to note, however, that changes in the exchange rate have a strong effect on trade patterns. For example, the table below calculates the import and export parity prices at different exchange rates using the (hypothetical) parity prices from the maize example above.

Exchange rate (LC/dollar)	Import parity price (US\$/ton)	Export parity price (US\$/ton)	Import parity price (LC/ton)	Export parity price (LC/ton)
35	235	165	8,225	5,775
40	235	165	9,400	6,600
45	235	165	10,575	7,425

The higher the exchange rate, the higher the LC import parity price, making it less likely that the country will import maize. If the exchange rate is high enough, the export parity price will rise above the autarky price making it profitable to export maize. For example, if the autarky price of maize is 9000 LC/ton, then with an exchange rate of 35 LC/US\$, it would import maize. With an exchange rate of 40 LC/US\$, it would neither import nor export maize. But if the exchange rate rose to 55 LC/US\$, the export parity price would rise to 9075 LC/ton (=55 x 165) and it would become profitable to export maize. This example is purely hypothetical, but it illustrates the impact of exchange rates on trade patterns and even on the direction of trade.

Modeling international trade with GAMS

In order to model international trade with GAMS, we need to convert the economic principles discussed above into equations in GAMS notation. In general terms, we need to change the supply-demand equilibrium model from Section 1 in four ways: 1) commodity balance equation must be modified, 2) we need to identify the relationship between domestic and world prices, 3) we need to establish a *complementarity relationship*, and 4) the associated variable must be listed as a POSITIVE VARIABLE.

With regard to the commodity balance equation, demand and supply are still equal to each other but they are defined more broadly to include international demand (exports) and international supply (imports). Using M for imports and X for exports, we can write the equation as:

$$S + M = D + X$$

With regard to the relationship between export price and domestic prices, we need to set the export parity price as the lower limit of domestic prices. Using PX as the FOB price, NER as the nominal exchange rate, and TC as the transportation cost to the port:

$$P + TC \geq NER * PX$$

The import parity price sets the upper limit. If PM is the CIF price, then:

$$PM*NER + TC \geq P$$

Third, in order to solve a model with inequalities, GAMS requires a *complementary relationship* between each inequality and a variable. The relationship between the two is complex, but what is important to know is that the export price relationship is “associated” with the export variable (X), while the import price relationship is associated with the import variable (M). In GAMS, this relationship is indicated in the solve command, where the equation and its “associated” variable are linked with a dot. This example is from SD2:

```
SOLVE MARKET / DEMAND
                SUPPLY
                IN-OUT
                EXPORTS.X / ;
```

Another example is found in the SDP4 program:

```
213 MODEL MARKET / DEMAND
214                SUPPLY
215                IN_OUT
216                DOM_TRADE.TQ
217                EXPORTS.X
218                IMPORTS.M
219                XQUOTA.IXT
220                MQUOTA.IMT / ;
```

Fourth, the associated variable must be listed separately from the other variables; it must be under the heading **POSITIVE VARIABLE**. For example, in SD2 the variables are listed as follows:

```
POSITIVE VARIABLES
  X      Exports (thousand tons) ;

VARIABLES
  P      Equilibrium price (LC per kg)
  D      Quantity demanded (thousand tons)
  S      Quantity supplied (thousand tons) ;
```

This tells GAMS that exports cannot be negative. GAMS will not be able to solve a model and will give an error message if 1) an inequality is not linked to the relevant variable in the SOLVE command and 2) if the linked variable is not listed in the POSITIVE VARIABLE command.

Economics of restrictions on international trade

Previously in Section 7, we assumed free trade. In other words, we assumed that the government did not intervene in the import and export markets. In this subsection, we examine how to model the effects of various types of trade restrictions on the markets. We focus on five types of policies: import taxes, export taxes, import quotas, export quotas, and changes in the exchange rate. Each is considered in turn. We adopt the “small country assumption” in this section. The effect of interventions under the “large country assumption” can be modeled like interventions in regional trade, considered in Section 10.

Import taxes: An import tax (also called an import tariff) raises the domestic price above the CIF price. At the higher domestic price, the quantity demanded is lower and the quantity supplied is higher. The combination of these two effects is that the volume of imports falls. Under the small country assumption, the

relationship between the domestic price and the CIF price is as follows:

$$P_d = \text{NER} * P_m * (1+t)$$

where P_d = the domestic price,
NER = the nominal exchange rate (in LC/foreign exchange unit)
 P_m = the CIF price in foreign currency units, and
t = the import tax rate.

This equation implies that an increase in the import tax causes a proportional increase in the domestic price. For example, raising the import tax from 0% to 10% will increase the domestic price by 10%. Under the large country assumption, the reduction in imports reduces the world price, so the increase in domestic prices is slightly *less* than proportional to the increase in the import tax. However, there are very few cases of countries that are “large” in any of their import markets.

Import tax revenue is equal to the tax rate multiplied by the value of imports.

$$\text{TR} = M * P_m * t$$

A small or medium import tax will generate tax revenue. However, a very large import tax will cause imports to decrease so much that tax revenue is decreased. In an extreme case, the import tax can be so high that imports are reduced to zero, eliminating tax revenue.

Export tax: An export tax *reduces* the domestic price below the FOB price. This is because the tax reduces exports, thus reducing total demand for the product. At the lower domestic price, the quantity supplied decreases and the quantity demanded increases. Both of these trends cause exports to decrease. Under the small country assumption, the domestic price is as follows:

$$P_d = \text{NER} * P_x * (1-t)$$

where P_d = the domestic price,
NER = the nominal exchange rate (in LC/foreign exchange unit)
 P_x = the FOB price in foreign currency units, and
t = the export tax rate.

Under the large country assumption, an export tax reduces the world price. Thus, the decrease in the domestic price is somewhat *less* than proportional to the tax.

As in the case of import taxes, small to medium export taxes generate tax revenue. However, it is possible for the export tax to be so high that exports are not profitable, eliminating both exports and export tax revenue.

Import quota: An import quota is a limit, imposed by the government, on the volume of imports of a product. We assume in this section that the quota is *binding*, meaning that the quota is less than the equilibrium level of imports. The effects of an import quota are less obvious than those of the import tax. The key to understanding the quota is that it reduces the availability of the good in the country. By reducing domestic supply, the import quota *raises* the domestic price above the CIF price. The domestic price rises until the supply (domestic production plus imports) equals demand. The effects of an import quota are very similar to those of an import tax. Both policies raise the domestic price, decrease the quantity demanded,

increase domestic quantity supplied, and decrease imports. In fact, the impact of an import quota can be measured by the *implicit import tax*, defined as the import tax an equivalent effect on domestic prices. For example, if an import quota on motorbikes raises the domestic price from US\$ 2000 to US\$ 2500, the implicit import tax is 25%.

Import quotas are valuable. For example, in the motorbike example above, a quota to import 1000 motorbikes would be worth US\$ 500,000. This is because the quota allows an importer to make a pure profit of US\$ 500 per motorbike. The profit associated with owning a scarce resource (in this case, quota allocations) is called *economic rent*. This rent creates a strong incentive for corruption since importers are willing to pay up to US\$ 500 per motorbike for import quotas.

Export quota: An export quota is a limit, imposed by the government, on the volume of exports of a product. Again, we assume that the export quota is binding. The export quota reduces the effective demand for the product by limiting exports. By limiting demand, the export quota *reduces* the domestic price below the FOB price. The domestic price falls until the demand (domestic demand plus exports) is equal to supply. The export quota reduces the quantity supplied and increases the quantity demanded, just like the export tax.

As in the case of the import quota, we can measure the impact of the export quota with the *implicit export tax*, defined as the export tax that would have the same effect on domestic prices. For example, if the export quota on rice reduces the domestic price from US\$ 250/ton to US\$ 200/ton, then the implicit export tax is 20%.

Like import quotas, export quotas are valuable. In the rice example above, a quota to export 100 thousand tons would be worth US\$ 5 million. This is economic rent. The incentive for corruption between exporters and those allocating the quotas is strong.

Exchange rate: The exchange rate is the price of one currency in terms of another currency. When we discuss the exchange rate, we refer to the number of local currency (LC) units per units foreign currency (such as the US dollar). Suppose the exchange rate is 40 LC/US\$. A *depreciation* of the exchange rate means increasing the number of local currency per unit of foreign currency. If the rate changed from 40 LC/US\$ to 45 LC/US\$, this would be a depreciation of the LC. An *appreciation* of the exchange rate is a decrease in the number of local currency units per unit of foreign currency, such as a change from 40 LC/US\$ to 35 LC/US\$.

As we showed earlier, depreciation of the local currency increases the domestic price of imported goods and exportable goods in the country. This increases the quantity supplied of imports and exports and reduces the demand for them. These changes in supply and demand increase exports and decrease imports. In contrast, an appreciation of the local currency decreases the domestic price of imported goods and exportable goods. This reduces the quantity supplied and increases the quantity demanded, thus making exports fall and imports rise.

Over time, currencies tend to depreciate when domestic inflation is higher than inflation in other countries and currencies tend to appreciate when domestic inflation is lower. For example, if inflation in the country is 20% and inflation in the US is 5%, then we expect the LC/US\$ exchange rate to depreciate at about 15%, if other factors remain unchanged. This relationship between inflation and the exchange rate is called *purchasing power parity*.

Simulating restrictions on international trade with GAMS

Import and export taxes: Representing import and export taxes in a GAMS model is relatively simple. The only change necessary is to put the tax rate into the parameter equation that describes the import and export prices in local currency. For example, in the program SDP1, the equation for the export price is as follows:

$$PX = \text{NER} * \text{WP} (1 - \text{TAX}) ;$$

In the SDP4 (see Annex 1), the equations for the import and export prices are similar:

$$\begin{aligned} 161 \quad PX(C) &= \text{NER} * \text{WP}(C, 'X') * (1 - \text{TAX}(C, 'X')) ; \\ 162 \quad PM(C) &= \text{NER} * \text{WP}(C, 'M') * (1 + \text{TAX}(C, 'M')) ; \end{aligned}$$

Import and export quotas: Representing import and export quotas in a GAMS model is somewhat more complex because it involves inequalities. The export and import quotas are represented as inequalities in the EQUATION section of a GAMS program. The following example comes from the SDP4 program (see Annex 1):

```
205 XQUOTA(C) ..
206     QUOTA(C, 'X') =G= SUM(R, X(C, R)) ;
207
208 MQUOTA(C) ..
209     QUOTA(C, 'M') =G= SUM(R, M(C, R)) ;
```

As discussed in Module IV, any inequality in GAMS must have a *complementarity relationship* with a variable that is positive when the inequality is binding. In the case of import and export quotas, the associated variables are the implicit import tax and the implicit export tax, respectively. The association between the inequalities and the variables is identified in the SOLVE section. This is illustrated by this example from the SDP4 program:

```
213 MODEL MARKET / DEMAND
214     SUPPLY
215     IN_OUT
216     DOM_TRADE.TQ
217     EXPORTS.X
218     IMPORTS.M
219     XQUOTA.IXT
220     MQUOTA.IMT / ;
```

IXT and IMT are variables representing the implicit export tax and the implicit import tax, respectively. These variables must be listed in the POSITIVE VARIABLE section as shown below:

```
169 POSITIVE VARIABLES
170     TQ(C,R,RR) Transported quantity (thousand tons)
171     IXT(C)      Implicit export tax (LC per kg)
172     IMT(C)      Implicit import tax (LC per kg)
173     X(C,R)      Exports (thousand tons)
174     M(C,R)      Imports (thousand tons) ;
```

And finally, the implicit tax variables appear in the equations that relate domestic prices to international prices. In the SDP4 program, these equations are as follows:

```
199 EXPORTS(C, R) ..
```

```

200      P(C,R) + IXT(C) + TCOST(R,'WORLD') =G= PX(C) ;
201
202      IMPORTS(C,R) . .
203      PM(C) + IMT(C) + TCOST('WORLD',R) =G= P(C,R) ;

```

PD is the consumer price, PS is the producer price, and the two MARG parameters are marketing margins.

Exchange rate: Modeling changes in the exchange rate is simple: we just change the parameter that represents the exchange rate. In the SDP4 and the smaller models used here, this parameter is called the NER, for nominal exchange rate. Although the price of commodities on the international market remains unchanged because of the small-country assumption, a change in the exchange rate will affect the domestic prices of tradable goods. For example, increasing the exchange rate from 40 Ngultrums/US\$ to 50 Ngultrums/US\$ would increase the local currency price of imported goods and exported goods. This would cause the demand for both goods to decline, while stimulating the supply of these goods. Decreasing the exchange rate would have the opposite effect.

Exercises for Section 7

13. The program SDP1 is a one-good one-market model with exports, export taxes, and export quotas. To see the equilibrium without restrictions, set the tax to zero and the quota to 10000 (to ensure that it is not binding).
 - What is the equilibrium price?
 - What is the quantity demanded?
 - What is the quantity supplied?
 - What is the level of exports?
14. Now impose an export quota of 2.7 million tons and run the program.
 - What is the equilibrium price?
 - What is the quantity demanded?
 - What is the quantity supplied?
 - What is the level of exports?
 - What is the implicit export tax?
 - Calculate the implicit export tax as a percentage of the no-quota equilibrium price.
 - Calculate the total value of the export quotas by multiplying the implicit export tax by the volume of exports.
15. Set the quota at 10000 again so it is not binding. Now impose an export tax of 0.1111 and run the program.
 - What is the equilibrium price?
 - What is the quantity demanded?
 - What is the quantity supplied?
 - What is the level of exports?
 - Compare the results under the 2.7 m ton quota and the 11.11% tax.
 - Calculate the export tax revenue by multiplying the tax rate by the price and by the volume of exports.
16. Open the program SD2. This program has one region, one product, and an export market.

What is the export price in US dollars/ton?

What is the exchange rate?

What is the export price in LC/kg?

Now run the model and answer the following questions:

What is the equilibrium quantity supplied?

What is the equilibrium quantity demanded?

What is the equilibrium price?

What is the level of exports?

SD1 used the same supply and demand equations as SD2, but there is no trade. Compare the results in SD1 and SD2.

17. Run a simulation using SD2 in which a drought reduces the harvest by 2 million tons (reduce the supply intercept by 2000).
What is the equilibrium quantity supplied?
What is the equilibrium quantity demanded?
What is the equilibrium price?
What is the level of exports?
How is this result different than the effect of the same drought on the model without exports in SD1?
18. Run a simulation in which income increases by 10%.
What is the equilibrium quantity supplied?
What is the equilibrium quantity demanded?
What is the equilibrium price?
What is the level of exports?
How is this result different than the effect of the same increase in demand on the model without exports in SD1?
19. Run a simulation in which the world price increases by \$30 per ton.
What is the equilibrium quantity supplied?
What is the equilibrium quantity demanded?
What is the equilibrium price?
What is the level of exports?
20. Open the program SD3. This program has one region, three goods, and import and export markets. Calculate the import and export prices in LC per kilogram.
21. Make two copies of the table giving the world prices. Use asterisks to “turn off” one copy. Change the other copy so the import prices are all \$1000 and the export prices are \$ 0 (this will “turn off” international trade). Run the model and write down the autarky prices. Based on the autarky prices and the import and export prices, predict which crops will be imported, which will be exported, and which will not be traded.
22. Now use asterisks to turn off the 0/1000 world prices and turn on the original world prices. Run the model. Check to see if your predictions were correct.
23. Suppose the world prices of cassava rises \$30 per ton to \$180 and \$280. What is the effect on cassava production, consumption, and prices?

SECTION 8: REGIONAL TRADE

Key words

Price differential, cost of transportation, domestic price relations, commodity balance, complementarity relationship, and implicit tax.

Economics of regional trade

In this section, we consider regional trade (trade between regions of a country), focusing on the relationship between transportation costs and regional price differences. Initially, we assume that there are no policy restrictions on regional trade. Later in Section 8, we consider the effect of restrictions on regional trade.

As discussed in Section 7, international trade and internal trade are very similar. Internal trade generally has fewer policy trade barriers and smaller transportation costs. In addition, the analysis of international trade often assumes that world prices are exogenous, but the analysis of regional trade does not make this assumption. For example, changes in the demand for rice in the Red River Delta affect the price of rice in the North Mountain and Midlands region. In addition, changes in the supply of rice in the Mekong River Delta affect the price of rice in Ha Noi. In a model of internal trade, all regional prices are endogenous.

Because there are no exogenous prices in a model of internal trade, there are no upper and lower limits on prices, as there are with international trade. Other aspects of the analysis are similar, however. The cost of moving goods from one region to another sets an upper limit on the difference in prices between the two regions, unless there are trade restrictions (trade restrictions are discussed in Module V). Why is this? If the *price differential* is larger than the cost of transporting goods from one region to another, traders will ship goods from the low-price region to the high-price region. This reduces the supply in the low-price region, pushing up the price there. At the same time, the trade increases the supply in the high-price region, pushing down the price in that region. This process continues as long as the price differential is greater than the total cost of transporting goods from one region to the other.

For example, if the cost of transporting rice from south to north is 500 LC/kg and the prices in the north are 3000 D/kg while the prices in the south are 2200 D/kg, traders will find it profitable to ship rice from the south to the north. Supplies will increase in the north and decrease in the south until the price difference is about 500 D/kg.

As in the case of international trade, if there is trade between two regions, the price differential will equal to the cost of transportation between the two regions. If the price differential is less than the cost of transportation, then there cannot be trade between the two regions.

Simulating regional trade with GAMS

In order to adapt a two-region one-good no-trade model to include trade between the regions, we need to make four modifications: 1) the commodity balance equation must be changed to incorporate regional flows, 2) we need to add inequalities that express the relationship among prices, 3) a *complementarity relationship* must be established, and 4) the variable associated with the equation must be listed as a POSITIVE VARIABLE.

First, the commodity balance equation must be modified to incorporate flows to and from the region. Supply is set equal to demand, but supply includes regional supplies and inflows, while demand includes regional demand and outflows. It is convenient to treat goods that are produced and consumed in the same region as

$$S_i + \sum_j TQ_{ji} = D_i + \sum_j TQ_{ij}$$

“flows” from region i to region j . Thus, the commodity balance equation is as follows: where TQ_{ij} is the transported quantities going from region i to region j . In GAMS notation, the equation may look like this example from SD4:

```
IN-OUT (R) ..
  S (R) + SUM (RR, TQ (RR, R)) - SUM (RR, TQ (R, RR)) =E= D (R) ;
```

Second, inequalities must be used to set upper limits on the price differentials of each pair of markets that can trade. If TC_{ij} is the cost of transporting goods from region i to region j , then the inequality is written as follows:

$$P_i + TC_{ij} \geq P_j$$

The program SD4 shows how this is expressed in GAMS notation:

```
DOMTRADE (R, RR) ..
  P (R) + TCOST (R, RR) =G= P (RR) ;
```

Third, as discussed in Section 7, an inequality can only be included in the model if it has a *complementary relationship* with a variable. The important thing to know is that the inequality representing the domestic price relationship is “associated” with the volume of inter-regional shipments (TQ). In GAMS, this relationship is indicated in the solve command, where the equation and its “associated” variable are linked with a dot. This example is from SD4:

```
MODEL MARKET / DEMAND
                  SUPPLY
                  INOUT
                  DOMTRADE.TQ / ;
```

And fourth, the variables associated with the inequalities must be listed under the command POSITIVE VARIABLES, as shown in the example below:

```
POSITIVE VARIABLES
  TQ (R, RR) Transported quantity (thousand tons) ;
```

Economics of restrictions on regional trade

In Section 7, we noted that modeling regional trade between countries is very similar to modeling trade among “large” countries. In both cases, the cost of transporting goods from one market to the other is the upper limit on the price differential between the markets, unless there are barriers to trade. If there is trade between the two markets, the price difference will equal the cost of transportation (including related costs of

marketing, return on capital, and a premium to cover risk) from the surplus market to the deficit market.

Restrictions on trade between regions can take the form of policies that raise the cost of moving goods (such as road and bridge tolls, checkpoints, and other additional expenses) or restrictions on the quantity of goods moved (such as quotas). In either case, the flow of goods is reduced. This increases the supply in the surplus region, thus reducing prices, while decreasing supply in the deficit region, thus increasing prices. The net effect is to increase the price difference between the two regions.

Information on the degree of restrictions on internal trade is often more difficult to obtain than information on international trade barriers. If tolls and other fees are collected by local authorities, it is more difficult to estimate the size of those costs. Similarly, data on the costs associated with delays due to police checkpoints and bureaucratic obstacles are not easy to collect.

Simulating restrictions on regional trade with GAMS

The most difficult part of modeling restrictions on regional trade is obtaining relevant data. Often the easiest approach is to infer the implicit costs related to restrictions on trade by comparing the observed price differentials with the actual cost of transportation. The difference between the two is a measure of the costs associated with restrictions on trade.

If we assume that marketing margins are fixed and that the costs associated with trade restrictions are fixed, then modeling the restrictions is simple. The total marketing margin between regions is represented by two components: the actual cost of transportation and the cost related to restrictions. In some models, for example, the actual transportation cost is calculated from distances between pairs of regions.

The implicit taxes (ITX) associated with the restrictions on trade are provided in another table in the SDP4 program (see lines 118-134). The implicit taxes are included in the margin between prices in one region and prices in another region in SDP4:

```
196  DOMTRADE (C, R, RR) . .  
197      P (C, R) + TCOST (R, RR) + ITX (C, R, RR) =G= P (C, RR) ;
```

Thus, the base scenario includes the effect of restrictions on internal trade. To simulate the removal of these restrictions, the equation in line 197 would be changed to exclude the implicit tax parameter (ITX).

Exercises for Section 8

1. The program SD4 is a two-region, one-good model with trade between the two regions.
What is the cost of transportation between north and south?
Can you tell from the intercepts the direction of trade?
 - a) north to south
 - b) south to north
 - c) both directions
 - d) neither directionWhich variable is “associated with” the domestic price inequality?
2. After the TCOST parameter, add an equation setting TCOST at 5000. This will make any regional

trade unprofitable, forcing each region to be self-sufficient. Save the file, run it, and look at the results.

What is the equilibrium price in the north?

What is the “equilibrium” price in the south?

3. With this self-sufficiency model, suppose there is a drought in the north and supply shift back 1 million tons. Run a simulation of this.
What is the equilibrium price in the north?
What is the “equilibrium” price in the south?
4. Now remove the line setting TCOST at 5000 and set the supply intercept in the north at its original level (7200) and run the program again.
What is the equilibrium price in the north?
What is the equilibrium price in the south?
What is the equilibrium level of trade?
5. Simulate the same drought in the north again, shifting back supply by 1 million tons. Run the model.
What is the equilibrium price in the north?
What is the equilibrium price in the south?
What is the equilibrium level of trade?
6. Compare prices with and without regional trade.
Compare the effects of the drought with and without trade.
7. Open the program SD5. This is a three-good two-region model with both international trade and regional trade. Run the program.
Which crops are exported, imported, and not traded?
Which crops are transported within the country and which direction (N to S or S to N)?
8. Suppose world maize prices rise by \$ 20 per ton. Increase *both* import and export prices to represent this change.
How does this affect maize trade in the north?
How does this affect maize trade in the south?
9. The program SDP3 is a two-region one-good model with regional trade and restrictions on internal trade. The internal restrictions are represented by the parameter ITX (implicit tax). This parameter increases the gap between the price in the south and the north, as seen in the equation DOMTRADE.

How much is the implicit tax on south-north trade?
Run the model and answer the following questions.
What is the price in the north?
What is the quantity demanded in the north?
What is the quantity supplied in the north?
What is the price in the south?
What is the quantity demanded in the south?
What is the quantity supplied in the south?
How much is transported from south to north?

10. Now we will simulate a policy which removes all restrictions on internal trade. This is represented by changing the values of ITX to zero. Run the model and answer the following.
 - What is the price in the north?
 - What is the quantity demanded in the north?
 - What is the quantity supplied in the north?
 - What is the price in the south?
 - What is the quantity demanded in the south?
 - What is the quantity supplied in the south?
 - How much is transported from south to north?
 - Compare this result to the results *with* restrictions in step 1.

11. Now we will simulate a policy which increases restrictions on internal trade. This is represented by changing the values of ITX to 2000. Run the model and answer the following.
 - What is the price in the north?
 - What is the quantity demanded in the north?
 - What is the quantity supplied in the north?
 - What is the price in the south?
 - What is the quantity demanded in the south?
 - What is the quantity supplied in the south?
 - How much is transported from south to north?

SECTION 9: INCOME AND WELFARE EFFECTS

Keywords

Cash income, non-cash income, gross income, net income, multiplier, farm-non-farm linkages, partial equilibrium model, and general equilibrium model.

In the models discussed so far, we assumed that household income was exogenous, meaning that income was assumed to be fixed. We know, however, that household income is partly determined by the production and price of agricultural crops. For example, if the price of a crop rises, farm income will rise, thus affecting demand patterns. In this section, we show how household income can be made endogenous in the model.

Making income endogenous

Income can be divided into two categories for the purpose of a model. The first category is income from the production of the good or goods represented in the model. The second category is income from all other sources. For example, if the model includes all farm products, it is useful to separate farm income from non-farm income. In such a model, farm income is endogenous, while non-farm income is exogenous. We now examine how farm income should be calculated.

The first question is whether we want the value of agricultural sales or the value of agricultural production. There is a difference between the two because part of agricultural production is retained by the household for consumption, animal feed, seed, or other uses. Since retained output is valuable to the household, we can think of this as non-cash income from agricultural production. It is generally assumed that demand patterns are affected by the level of total income, including both cash and non-cash income. Therefore, when we calculate income, we want to use the value of agricultural production, not just agricultural sales.

The second question is whether to use the gross value of agricultural production or the net value. The net value is the gross value minus the costs of production. Since demand is a function of the amount of *disposable* income, we are interested in the *net* value of farm production, where net is defined as gross minus the costs of fertilizer, pesticides, seed, rented land, rented machinery, and hired labor. The net value of farm production is the return on family labor, family-owned machinery, and family-owned land.

The third question is how to calculate the net value of production. The gross value of production for a given crop is simply the price multiplied by the quantity produced, both of which are available from the models discussed in Modules 1 to 5. There are two ways to calculate the net value from the gross value.

- 1) Economic theory indicates the cost of producing quantity Q is the area under the supply curve and to the left of Q . This method is useful for estimating the *change* in net income when prices or quantity change, but not for estimating *total* net income because we do not have good information on the shape of the supply curve for very low prices.
- 2) Studies of the cost of production may indicate the costs of inputs, hired labor, and rented land as a proportion of the value of output. We can assume that this ratio is constant over the relevant range of prices and quantities.

Calculating the welfare impact

For a household that consumes a good but doesn't produce it, the welfare impact of a price change can be measured using the consumer surplus, defined as the area behind the demand curve between the two price lines. We define CS to be negative when the price increases. A first-order approximation of the consumer surplus is:

$$CS = -q_d(p_1 - p_0) = -q_d \Delta p$$

where Δp is the change in price and q_d is the original quantity demanded (consumed). This is the welfare impact of a price change assuming that the consumer cannot respond to the change by adjusting consumption. Geometrically, it is a rectangular approximation of the area behind the curve.

The second-order approximation takes into account the response of consumers to the higher price. It is a parallelogram approximation of consumer surplus. It is an approximation because it assumes the demand curve is linear.

$$CS = -q_d \Delta p - 0.5(\Delta p)(\Delta q_d)$$

We can rewrite this expression in terms of elasticities:

$$CS = -(q_d p_0) \frac{\Delta p}{p_0} - 0.5 \varepsilon_D q_d p_0 \left(\frac{\Delta p}{p_0} \right)^2$$

Next, we can write the proportional welfare impact as the consumer surplus as a proportion of income.

$$\frac{CS}{y} = -(\text{CBR}) \frac{\Delta p}{p_0} - 0.5 \varepsilon_D (\text{CBR}) \left(\frac{\Delta p}{p_0} \right)^2$$

where CBR is the *consumption benefit ratio*, defined as the value of the consumption of the good as a proportion of total income, and ε_D is the price elasticity of demand.

The second-order approximation of the producer surplus is similar:

$$PS = (q_s p_0) \Delta \frac{p}{p_0} + 0.5 \varepsilon_S q_s p_0 \left(\frac{\Delta p}{p_0} \right)^2$$

except that the signs are positive. This is because a price increase has a positive effect on the welfare of a producer. By the same transformation as above, we can write the producer surplus as a proportion of income.

$$\frac{PS}{y} = (PBR) \frac{\Delta p}{p_0} + 0.5 \varepsilon_S (PBR) \left(\frac{\Delta p}{p_0} \right)^2$$

where PBR is the *production benefit ratio*, defined as the share of income coming from the production of the good, and ε_S is the price elasticity of supply.

We can combine these two equations to get the net welfare impact on a household as both producer and consumer.

$$\frac{CS+PS}{y} = (PBR - CBR) \frac{\Delta p}{p_0} + 0.5 (\varepsilon_S PBR - \varepsilon_D CBR) \left(\frac{\Delta p}{p_0} \right)^2$$

If we defined the PBR and the CBR as parameters for each commodity and each region, then the welfare impact of a change in a given commodity price on a region could be calculated in GAMS as follows:

$$\begin{aligned} WELF(R) = & PCTDP('RICE', R) * (PBR('RICE', R) - CBR('RICE', R)) \\ & + 0.5 * (ELAST_S(C) * PBR('RICE', R) - ELAST_D(C) * CBR('RICE', R)) \\ & * (PCTDP('RICE', R) ** 2); \end{aligned}$$

where WELF(R) is the welfare impact in region R,

PCTDP{,RICE',R) is the percentage change in rice price in region R from the model solution

PBR(,RICE',R) is the production benefit ratio for rice in region R

CBR(,RICE',R) is the consumption benefit ratio for rice in region R

ELAST_S(C) is the elasticity of supply of commodity C, and

ELAST_D(C) is the price elasticity of demand of commodity C.

Welfare impact on different household groups

With household-level data on the patterns of production and consumption of each agricultural commodity, we can further disaggregate the results to calculate the impact of price changes on different types of households within each region. For example, it is very likely that the CBR of staple food commodities is larger for poor households than rich households, so the relative impact of a food price increase on a poor urban household would be greater than for a rich urban household. Similarly, the PBR for a farmer will be higher than the PBR for a salaried worker. We can modify the GAMS commands above to take into account different types of households, provided we can also disaggregate PBR and CBR by household group.

$$\begin{aligned} WELF(R, H) = & PCTDP('RICE', R) * (PBR('RICE', R, H) - CBR('RICE', R, H)) \\ & + 0.5 * (ELAST_S(C) * PBR('RICE', R, H) - ELAST_D(C) * CBR('RICE', R, H)) \\ & * (PCTDP('RICE', R) ** 2); \end{aligned}$$

where WELF(R,H) is the welfare impact on household type H in region R,

PCTDP{,RICE',R) is the percentage change in rice price in region R from the model solution

PBR(,RICE',R,H) is the production benefit ratio for rice among household type H in region R

CBR(R ,RICE', R , H) is the consumption benefit ratio for rice among household type H in region R
 ELAST_S(C) is the elasticity of supply of commodity C , and
 ELAST_D(C) is the price elasticity of demand of commodity C .

Exercises for Section 9

1. Open the file SDY1. This program has an exogenous original income (Y_0) and an endogenous income (Y) calculated from the farm price and the supply (it assumes that there are no costs of production so net income equals gross income). Notice that in this version of the program, endogenous income is calculated in the INCOME equation. However, the endogenous income does not appear in any other equation: income is calculated but not used. The demand equation uses the *exogenous original income*. Run the model and record the results.
2. Simulate an increase in supply of 1.5 million tons (hint: increase SA by 1500). Run the model and record the results. Why does income (gross revenue) fall when the supply increases? Is this always true or does it depend on the particular elasticities in this model? What elasticity determines whether an increase in supply raises or lowers income?
3. Change Y_0 to Y in the INCOME equation. This makes demand a function of the endogenous income, creating feedback from supply to income to demand. Run the program once with the original supply curve ($SA = 13500$) and with the higher supply curve ($SA = 13500$). Compare the original supply results with and without the income effect. Why is there no difference? Now compare the higher supply results with and without the income effect. Why does the increase in supply make the price lower when income is endogenous than when it is exogenous? Why does the increase in supply make the quantity lower when income is endogenous than when it is exogenous?
4. The program SDY3 is a model of supply and demand for one good and one region with endogenous income. Instead of specifying the supply and demand parameters directly, it specifies the elasticities and the original price, consumption, and production and calculates the supply and demand parameters from these numbers.

Assume that the consumption and production benefit ratios are as follows:

	Cons benefit ratio	Prod benefit ratio
Poor households	0.40	0.50
Rich households	0.10	0.20

Write equations to calculate the first- and second-order approximation of the welfare impact of price changes on poor and rich households. You can call the new parameters WELFP1, WELFP2, WELFR1, and WELFR2.

5. After perfecting the welfare impact calculation, simulate an increase in the supply by increasing the value of S_0 by 3000. How does it affect the welfare of poor and rich households? Why are the second-order approximations more positive than the first-order approximations?
6. Now change the price elasticity of demand to -2.0 and run the simulations of the two supply situations (original and higher supply). How does the shift affect poor and rich households now?

Annex 1: Example of an agricultural sector model

```
* FILE: SDP4
* GAMS PROGRAM TO SIMULATE SUPPLY AND DEMAND FOR FOUR GOODS
* IN SIX REGIONS WITH INTERNAL TRADE, IMPORTS AND EXPORTS
* WITH TRADE TAXES AND QUOTAS AND REGIONAL TRADE RESTRICTIONS
* Note: LC refers to local currency units.
```

```
OPTION LIMCOL = 0 ;
OPTION LIMROW = 0 ;
$OFFSYMLIST ;
$OFFSYMXPREF ;
```

```
SET
  C      Crops /Rice
           Maize
           Mustard
           Citrus /
  RW     Region including world
           /WEST
           CENTRAL
           EAST
           S_WEST
           S_CENT
           S_EAST
           WORLD /
  R(RW)  Region
           /WEST
           CENTRAL
           EAST
           S_WEST
           S_CENT
           S_EAST /;
```

```
ALIAS (R,RR), (RW,RRW) ;
```

```
TABLE P0(C,R)  Original price (LC per kg)
              WEST  CENTRAL  EAST      S_WEST  S_CENT  S_EAST
RICE         2987   2982    2756    2636    2354    2368
MAIZE        2112   1988    1882    1439    1321    1694
MUSTARD      1553   1372    1003    1245     731     731
Citrus       535    473     499     584     486     486 ;
```

```
TABLE WP(C,*)  World price (US$ per ton)
              X      M
Rice         270    320
Maize        126    141
Mustard       0     150
Citrus       32    100 ;
```

```
TABLE TAX(C,*)  Trade tax (fraction)
              X      M
Rice         .01    .00
Maize        .00    .00
Mustard      .00    .00
Citrus       .00    .00 ;
```

```
TABLE QUOTA(C,*)  Trade quota (1000 tons)
```

	X	M
Rice	3000	9999
Maize	9999	9999
Mustard	9999	9999
Citrus	9999	9999 ;

TABLE DPE(C,R)	Price elasticity of demand					
	WEST	CENTRAL	EAST	S_WEST	S_CENT	S_EAST
Rice	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0
Maize	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0
Mustard	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0
Citrus	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0 ;

TABLE DYE(C,R)	Income elasticity of demand					
	WEST	CENTRAL	EAST	S_WEST	S_CENT	S_EAST
Rice	1.0	1.0	1.0	1.0	1.0	1.0
Maize	1.0	1.0	1.0	1.0	1.0	1.0
Mustard	1.0	1.0	1.0	1.0	1.0	1.0
Citrus	1.0	1.0	1.0	1.0	1.0	1.0 ;

TABLE SPE(C,R)	Price elasticity of supply					
	WEST	CENTRAL	EAST	S_WEST	S_CENT	S_EAST
Rice	1.0	1.0	1.0	1.0	1.0	1.0
Maize	1.0	1.0	1.0	1.0	1.0	1.0
Mustard	1.0	1.0	1.0	1.0	1.0	1.0
Citrus	1.0	1.0	1.0	1.0	1.0	1.0 ;

TABLE D0(C,R)	Original demand (1000 tons)					
	WEST	CENTRAL	EAST	S_WEST	S_CENT	S_EAST
RICE	2445	1522	1121	497	1189	2593
MAIZE	187	130	100	54	51	128
MUSTARD	315	367	132	56	75	225
CITRUS	319	248	188	77	82	217 ;

TABLE S0(C,R)	Original supply (1000 tons)					
	WEST	CENTRAL	EAST	S_WEST	S_CENT	S_EAST
RICE	2571	1190	973	238	520	7129
MAIZE	183	110	50	102	198	75
MUSTARD	398	450	144	71	10	115
CITRUS	45	210	331	258	501	70 ;

TABLE TCOST(RW,RRW)	Cost of transportation (LC per kg)						
	WEST	CENTRAL	EAST	S_WEST	S_CENT	S_EAST	WORLD
WEST	0	149	9999	9999	230	233	67
CENTRAL	149	0	325	9999	9999	9999	189
EAST	9999	325	0	173	294	364	294
S_WEST	9999	9999	173	0	164	9999	164
S_CENT	230	9999	294	164	0	47	35
S_EAST	233	9999	364	9999	47	0	35
WORLD	67	189	294	164	35	35	0 ;

PARAMETERS

DA Intercept of demand equation

DB Price coefficient of demand equation

DC Income coefficient of demand equation

SA Intercept of supply equation

SB Price coefficient of supply equation

NER Nominal exchange rate (LC per US\$)

PX(C) Export price (LC per kg)

PM(C) Import price (LC per kg)

Y0(R) Expenditure in 1995 (m LC per capita)

Y92(R) Expenditure in 1992-93 (m LC per capita)

	/ WEST	1.102
	CENTRAL	0.871

```

                EAST      1.267
                S_WEST    1.481
                S_CENT    1.840
                S_EAST    1.469 / ;

Y0(R) = 1.6*Y92(R) ;
DB(C,R) = DPE(C,R)*D0(C,R)/P0(C,R) ;
DC(C,R) = DYE(C,R)*Y0(R)/P0(C,R) ;
DA(C,R) = D0(C,R) - DB(C,R)*P0(C,R) - DC(C,R)*Y0(R) ;
SB(C,R) = SPE(C,R)*S0(C,R)/P0(C,R) ;
SA(C,R) = S0(C,R) - SB(C,R)*P0(C,R) ;
NER = 10;
PX(C) = NER*WP(C,'X')*(1-TAX(C,'X')) ;
PM(C) = NER*WP(C,'M')*(1+TAX(C,'M')) ;

VARIABLES
P(C,R)      Equilibrium price (LC per kg)
D(C,R)      Quantity demanded (thousand tons)
S(C,R)      Quantity supplied (thousand tons) ;

POSITIVE VARIABLES
TQ(C,R,RR)  Transported quantity (thousand tons)
IXT(C)      Implicit export tax (LC per kg)
IMT(C)      Implicit import tax (LC per kg)
X(C,R)      Exports (thousand tons)
M(C,R)      Imports (thousand tons) ;

EQUATIONS
DEMAND      Demand equation
SUPPLY      Supply equation
IN_OUT      Shipments into and out of region
DOM_TRADE  Domestic trade price relationships
EXPORTS     Export price relationships
IMPORTS     Import price relationships
XQUOTA     Export quota
MQQUOTA     Import quota ;

DEMAND(C,R)..
D(C,R) =E= DA(C,R) + DB(C,R)*P(C,R) + DC(C,R)*Y0(R) ;
SUPPLY(C,R)..
S(C,R) =E= SA(C,R) + SB(C,R)*P(C,R) ;
IN_OUT(C,R)..
S(C,R) + SUM(RR,TQ(C,RR,R)) - SUM(RR,TQ(C,R,RR)) - X(C,R) + M(C,R)
=E= D(C,R) ;
DOM_TRADE(C,R,RR)..
P(C,R) + TCOST(R,RR) =G= P(C,RR) ;
EXPORTS(C,R)..
P(C,R) + IXT(C) + TCOST(R,'WORLD') =G= PX(C) ;
IMPORTS(C,R)..
PM(C) + IMT(C) + TCOST('WORLD',R) =G= P(C,R) ;
XQUOTA(C)..
QUOTA(C,'X') =G= SUM(R,X(C,R)) ;
MQQUOTA(C)..
QUOTA(C,'M') =G= SUM(R,M(C,R)) ;
TQ.FX(C,R,R) = 0 ;

MODEL MARKET / DEMAND
                SUPPLY
                IN_OUT
                DOM_TRADE.TQ
                EXPORTS.X
                IMPORTS.M
                XQUOTA.IXT
                MQQUOTA.IMT / ;
SOLVE MARKET USING MCP ;

```