PART II

STRUCTURE OF GTAP FRAMEWORK

CHAPTER 2

Structure of GTAP

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I Introduction and overview

The purpose of this chapter is to develop the basic notation, equations, and intuition behind the GTAP model of global trade. The computer program documenting the basic model, GTAP94.TAB, is available in electronic form via the Internet (see Chapter 6). It provides complete documentation of the theory behind the model, and when converted to executable files using the GEMPACK software suite (Harrison and Pearson 1994), it forms the basis for implementing the applications outlined in Part III of this book.

The organization of this chapter is as follows. We begin with an overview of the Global Trade Analysis Project (GTAP) model. Next, we develop the basic accounting relationships underpinning the data base and model. This involves tracking value flows through the global data base, from production and sales to intermediate and final demands. Careful attention is paid to the prices at which each of these flows is evaluated, and the presence of distortions (in the form of taxes and subsidies). The relationship between these accounting relationships and equilibrium conditions in the model is then developed. This leads naturally into a discussion of the implications of alternative "partial equilibrium" closures whereby these equations are selectively omitted and the associated complementary variables are fixed. The chapter then turns to the linearized representation of these accounting relations. This is the form in which they are implemented in GEMPACK, which solves the nonlinear equilibrium problem via successive updates and relinearizations.

Section VI of this documentation turns its attention to the equations underpinning economic behavior in the model. We deal in turn with production, consumption, global savings, and investment. There is also a special discussion of macroeconomic closure in the GTAP model. This material is reinforced in the closing section of the chapter by means of a numerical example using a three-region, three-commodity aggregation, in which there is a shock to a single bilateral protection rate.

II Overview of the model[1]

Closed economy without taxes

Figure 2.1 offers an overview of economic activity in a simplified version of the GTAP model [see Brockmeier (1996) for a more comprehensive, graphical

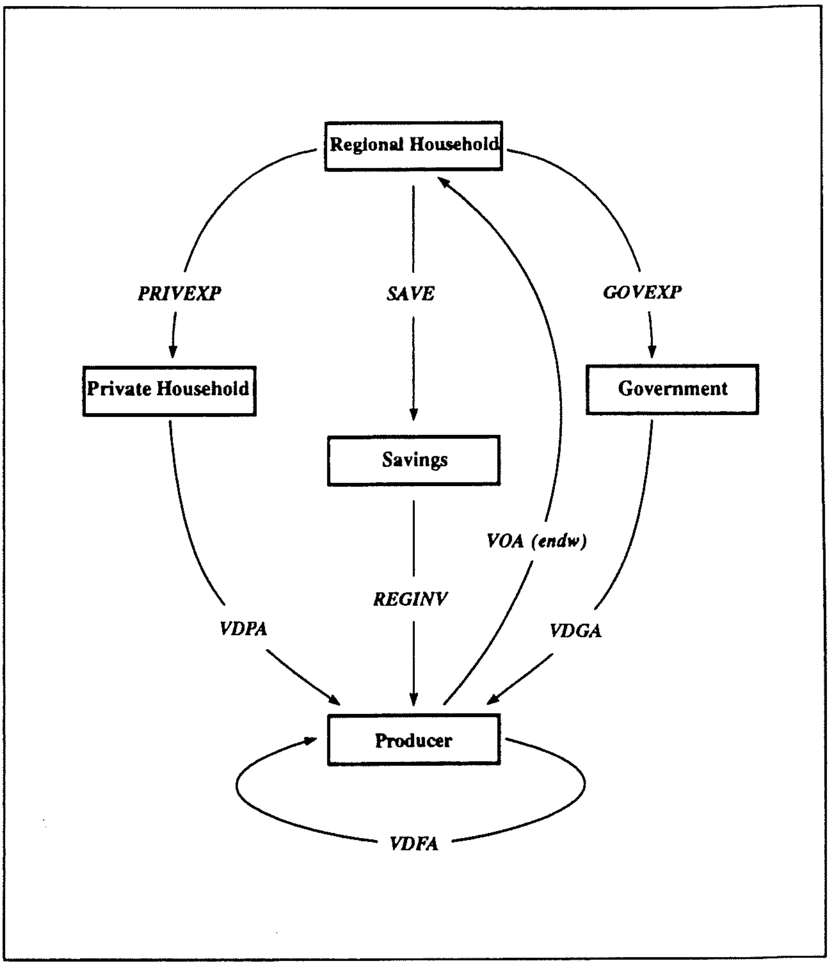


Figure 2.1. One-region closed economy without government intervention.

overview]. In this first figure, there is only one region, so there is no trade. There is also no depreciation, and no taxes or subsidies are present. At the top of this figure is the regional household. Expenditures by this household are governed by an aggregate utility function that allocates expenditure across three broad categories: private, government, and savings expenditures.[2] The model user has some discretion over the allocation of expenditures across these types of final demand. In the standard closure, the regional household's Cobb–Douglas utility function assures constant budget shares are devoted to each category. However, real government purchases and savings can also be dictated exogenously (i.e., fixed or shocked), in which case private household expenditure will adjust to satisfy the regional household's budget constraint.

This formulation for regional expenditure has some distinct advantages, as well as some disadvantages. Perhaps the most significant drawback is the failure to link government expenditures to tax revenues. Cutting taxes by no means implies a reduction in government expenditures in the GTAP model. Indeed, to the extent that these tax cuts lead to a reduction in excess burden, regional real income will increase and real government expenditure will likely also rise. This lack of fiscal integrity is dictated by the fact that the GTAP data have incomplete coverage of regional tax instruments. Therefore the model cannot accurately predict what will happen to total tax revenue, and the user who is interested in focusing on government expenditure effects would be required to make some exogenous assumptions in any case.

The greatest advantage of the formulation of regional expenditure displayed in Figure 2.1 is the unambiguous indicator of welfare offered by the regional utility function. A particular simulation might lead to lower relative prices for savings and the composite of government purchases, and higher prices for the private household's commodity bundle. If real private purchases fall, while savings and government consumption rise, is the regional household better off? Without a regional utility function we cannot answer this question.

An alternative approach to this problem of welfare measurement involves fixing the level of real savings and government purchases, and focusing solely on private household consumption as an indicator of welfare. However, private consumption is only slightly more than 50% of final demand in some regions. Forcing all the adjustment in the regional economy's final demand into private consumption seems rather extreme. We believe that the assumption of fixed expenditure shares dictated by the Cobb–Douglas regional expenditure function is more acceptable empirically. That is, a rise in income implies an increase in savings and government expenditures, as well as private consumption.

Since Figure 2.1 assumes the absence of taxes, the only source of income for regional households is from the "sale" of endowment commodities to firms. This income flow is represented by *VOA(endw)* which denotes *Value of Output at Agents' prices* of endowment commodities. (A complete glossary of GTAP notation is provided at the end of this book.) Firms combine these endowment commodities with intermediate goods (*VDFA* = *Value of Domestic purchases by Firms at Agents' prices*) in order to produce goods for final demand. This involves sales to private households (*VDPA* = *Value of Domestic purchases by Private households at Agents' prices*), government households (*VDGA* = *Value of Domestic purchases by Government household at Agents, prices*), and the sale of investment goods to satisfy the regional household's demand for savings (*REGINV*). This completes the circular flow of income, expenditure, and production in a closed economy without taxes.

Open economy without taxes

Figure 2.2 [also taken from Brockmeier (1996)] introduces international trade by adding another region, *Rest of the World* (ROW), at the bottom of the figure. This region is identical in structure to the domestic economy, but details are suppressed in Figure 2.2. It is the source of imports into the regional economy, as well as the destination for exports (*VXMD* = *Value of eXports at Market prices by Destination*). It is important to note that imports are traced to specific agents in the domestic economy, resulting in distinct import payments to ROW from private households (*VIPA*), government households (*VIGA*), and firms (*VIFA*). This innovation departs from most models of global trade, and was adopted from the SALTER model (Jomini et al. 1991). It is especially important for the analysis of trade policy in regions where import intensities for the same commodity vary widely across uses.

In moving from a closed to an open economy, we also require the introduction of two global sectors, one of which is displayed in Figure 2.2. The *global bank*, shown in the center of this figure, intermediates between global savings and regional investment. As will be discussed in more detail below, it assembles a portfolio of regional investment goods, and sells shares in this portfolio to regional households in order to satisfy their demand for savings.

The second global sector (not shown in Figure 2.2) accounts for international trade and transport activity. It assembles regional exports of trade, transport, and insurance services and produces a composite good used to move merchandise trade among regions. The value of these services precisely exhausts the differences between global *fob* exports, and global imports, evaluated on a *cif* basis.

III Accounting relationships in the "levels"

Distribution of sales to regional markets

The basic accounting relationships in the data base/model are best understood in the context of a flow chart. For example, Table 2.1 portrays the sources of

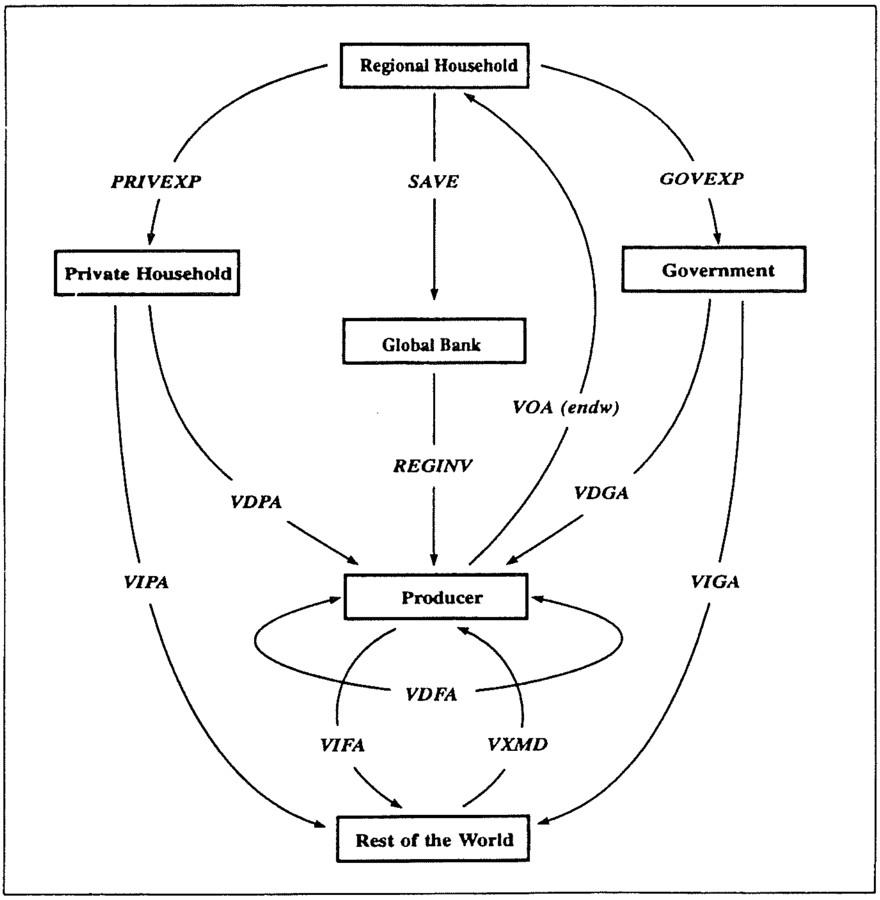


Figure 2.2. Multiregion open economy without government intervention.

sectoral receipts in the global data base. (In the data and the model all sectors produce a single output. Thus there is a one-to-one relationship between producing sectors and commodities.) At the top of the figure, *VOA*(*i*,*r*) refers to the *Value of Output at Agents' Prices.* (The general explanation for this choice of notation is as follows: value/type of transaction/type of price. See the appendix to this book for an exhaustive listing of variables used in the model and their description.) *VOA*(*i*,*r*) represents the payments received by the firms in industry *i* of region *r*. As we will see, these payments must be precisely exhausted on costs, under the zero pure profits assumption. The terms *PS*(*i*,*r*) and *QO*(*i*,*r*) to the right of *VOA* represent the price and quantity indices that make up *VOA*. They will be discussed in more detail below.

Table 2.1. ***Distribution of Sales to Regional Markets ($i \in TRAD$)***

		$VOA(i,r)$	$: PS(i,r) * QO(i,r)$
		$\underline{+PTAX(i,r)}$	
Domestic market r		$= VOM(i,r)$	$: PM(i,r) * QO(i,r)$
	$VDM(i,r)$		$VST(i,r)$
		$VXMD(i,r,s)$	$:PM(i,r) * QXS(i,r,s)$
		$\underline{+XTAXD(i,r,s)}$	
		$= VXWD(i,r,s)$	$: PFOB(i,r,s) * QXS(i,r,s)$
World market		$\underline{+VTWR(i,r,s)}$	
		$= VTWS(i,r,s)$	$: PCIF(i,r,s) * QXS(i,r,s)$
		$\underline{+MTAX(i,r,s)}$	
		$= VIMS(i,r,s)$	$: PMS(i,r,s) * QXS(i,r,s)$
		$VIM(i,s)$	$: PIM(i,s) * QIM(i,s)$
Domestic market s		$= VIPM(i,s)$	$: PIM(i,s) * QPM(i,s)$
		$+ VIGM(i,s)$	$: PIM(i,s) * QGM(i,s)$
	$+ \sum_{j \in PROD}$	$VIFM(i,j,s)$	$: PIM(i,s) * QFM(i,j,s)$
Where:	$VDM(i,r)$	$= VDPM(i,r)$	$: PM(i,r) * QPD(i,r)$
		$+ VDGM(i,r)$	$: PM(i,r) * QGD(i,r)$
	$+ \sum_{j \in PROD\_COMM}$	$VDFM(i,j,r)$	$: PM(i,r) * QFD(i,j,r)$

If one adds back the producer tax (or deducts the subsidy) denoted by *PTAX(i,r)*, then we arrive at the *Value of Output at Market prices, VOM(i,r)*. This may be seen to be the sum of the *Value of Domestic sales at Market prices, VDM(i,r)*, and the exports to all destinations, denoted as *Value of eXports of i from r evaluated at domestic Market prices (in r), and Destined for s, VXMD(i,r,s)*. In addition, we must take account of possible sales to the international transport sector, denoted *VST(i,r)*. These sales are designed to cover the international transport margins. They are evaluated at market prices and face no further (border) taxes. Similarly, since domestic sales do not cross a border, they do not face such taxes either.

In order to convert exports to *fob* values, it is necessary to add the export tax, denoted *XTAX(i,r,s)*. Note that these taxes are written in a form that is destination-specific. The data base exhibits destination/source-specific trade policy measures at the level of *disaggregated* regions and commodities (this varies by type of policy intervention). Once the data base has been aggregated over either commodities or regions, bilateral rates of taxation will vary due to compositional differences. Therefore, it is important to maintain this bilateral detail in the modeling framework. Once the export taxes are added in, we obtain the *Value of eXports at World prices by Destination, VXWD(i,r,s)*. The difference between this and the *cif*-based *Value of Imports at World prices by Source, VIWS(i,r,s)*, is the international transportation margin: *VTWR(i,r,s)* refers to the *Value of Transportation at World prices by Route* for commodity *i*, shipped from *r* to *s*.

At this point we have taken commodity *i* from its sector of origin in region *r* to its export destination in region *s*. In order to evaluate these sales at internal domestic prices in *s*, it is necessary to add import taxes, *MTAX(i,r,s)* to get *VIMS(i,r,s)*, the *Value of Imports at Market prices by Source*. These imports from alternative sources may then be combined into a single composite, *VIM(i,s)*, the *Value of Imports of i into s at Market prices*. Just as sales in the *r*th market had to be distributed across various destinations, so composite imports of *i* into *s* must be distributed across sectors and households in the *s*th market. Possible uses of imports include: *VIPM(i,s)* – the *Value of Imports by Private households, evaluated at Market prices; VIGM(i,s)* – the *Value of Imports by the Government, evaluated at Market prices*; and *VIFM(i,j,s)* – the *Value of Imports by Firms in industry j, at Market price*. In a similar fashion, domestic sales, denoted *VDM(i,r)*, must be distributed across private household, government, and firms' uses, as shown at the bottom of Table 2.1.

Sources of household purchases

Having distributed sales across various markets and taken full account of intervening taxes and transport margins, we are now in a position to consider household and firms' purchases within each of these individual markets. Table 2.2 outlines the distribution of household purchases of tradeable commodities. The top half of this figure pertains to private household purchases, denoted *VPA(i,s)*, to represent the *Value of Private household purchases at Agents' prices*. This represents the sum of expenditures on domestically produced goods, *VDPA(i,s)*, and composite imports, evaluated at agents' prices, *VIPA(i,s)*. Once private household commodity taxes, *IPTAX(i,s)*, are deducted, this brings us to the *Value of Imports by the Private household at Market*

Table 2.2. ***Sources of Household Purchases (i ∈ TRAD)***

Private household

	$VPA(i,s)$		$: PP(i,s) * QP(i,s)$
$VDPA(i,s)$	$: PPD(i,s) * QPD(i,s)$	$VIPA(i,s)$	$: PPM(i,s) * QPM(i,s)$
$-\underline{DPTAX(i,s)}$		$-\underline{IPTAX(i,s)}$	
$= VDPM(i,s)$	$: PM(i,s) * QPD(i,s)$	$= VIPM(i,s)$	$: PIM(i,s) * QPM(i,s)$

Government household

	$VGA(i,s)$		$: PG(i,s) * QG(i,s)$
$VDGA(i,s)$	$: PGD(i,s) * QGD(i,s)$	$VIGA(i,s)$	$: PGM(i,s) * QGM(i,s)$
$-\underline{DGTAX(i,s)}$		$-IGTAX(i,s)$	
$= VDGM(i,s)$	$: PM(i,s) * QGD(i,s)$	$= VIGM(i,s)$	$: PIM(i,s) * QGM(i,s)$

prices, *VIPM(i,s)*, which is the point where we left Table 2.1. Similarly, deducting domestic commodity taxes, *DPTAX(i,s)*, from *VDPA(i,s)* yields *VDPM(i,s)*, the *Value of Domestic purchases by the Private household, at Market prices.* Thus we have completed the link between industry sales at agents' prices (top of Table 2.1) and private household purchases at agents' prices (top of Table 2.2). The bottom half of Table 2.2 is completely analogous; only *P* is replaced by *G* in order to represent purchases by the government household.

Sources of firms' purchases and household factor income

Next, turn to firms' purchases of intermediate and primary factors of production. The top of Table 2.3 tackles the intermediate inputs, starting with the *Value of Firms' purchases of i, by sector j, in region s at Agents' prices,*

Table 2.3. *Sources of Firms' Purchases* $(j \in PROD)$

$i \in TRAD$: Intermediate inputs

	$VFA(i,j,s)$		$: PF(i,j,s) * QF(i,j,s)$
$VDFA(i,j,s)$	$: PFD(i,j,s) * QFD(i,j,s)$	$VIFA(i,j,s)$	$: PFM(i,j,s) * QFM(i,j,s)$
$-DFTAX(i,j,s)$		$-IFTAX(i,j,s)$	
$= VDFM(i,j,s)$	$: PM(i,s) * QFD(i,j,s)$	$= VIFM(i,j,s)$	$: PIM(i,s) * QFM(i,j,s)$

$i \in ENDW$: Primary factor services

$VFA(i,j,s)$	$: PFE(i,j,s) * QFE(i,j,s)$
$-ETAX(i,j,s)$	
$= VFM(i,j,s)$	$: PM(i,s) * QFE(i,j,s)$

Zero pure profits

$$VOA(j,s) = \sum_{i \in TRAD} VFA(i,j,s) + \sum_{i \in ENDW} VFA(i,j,s)$$

VFA(i,j,s). This may be broken into the domestic and imported components, *VDFA(i,j,s)* and *VIFA(i,j,s)*. Deducting intermediate input taxes, *DFTAX(i,j,s)* and *IFTAX(i,j,s)*, reduces these values to market prices, *VDFM(i,j,s)* and *VIFM(i,j,s)*, which are the same as the values reported at the bottom of Table 2.1.

Firms also purchase services of nontradeable commodities, which in this model are termed *endowment commodities*. (In the current data base, these include: agricultural land, labor, and capital.) The next part of Table 2.3 traces the value flows from the firms employing these factors of production, back to the households supplying them. Note that by deducting taxes on endowment

Table 2.4. ***Sources of Household Factor Service Income***

$i \in ENDWM$: Mobile endowments

$\sum_{j \in PROD} VFM(i,j,s)$	$= VOM(i,s)$	$: PM(i,s) * QO(i,s)$
	$- \underline{HTAX(i,s)}$	
	$= VOA(i,s)$	$: PS(i,s) * QO(i,s)$

$i \in ENDWS$: Sluggish endowments

$VFM(i,j,s)$	$: PMES(i,j,s) * QOES(i,j,s)$
$VOM(i,s)$	$: PM(i,s) * QO(i,s)$
$- \underline{HTAX(i,s)}$	
$= VOA(i,s)$	$: PS(i,s) * QO(i,s)$

i used in industry *j*, *ETAX(i,j,s)*, we can move from the *Value of Firms' purchases at Agents' prices, VFA(i,j,s)*, to the *Value of Firms' purchases at Market prices, VFM(i,j,s)*. The final section of Table 2.3 makes the link between firms' receipts [i.e., *VOA(j,s)*], as developed in Table 2.1, and firms' expenditures [i.e., *VFA(i,j,s)*], as shown in Table 2.3. Zero pure economic profits means that revenues must be exhausted on expenditures, once accounting for all tradeable (i.e., intermediate) inputs and endowment (i.e., primary) factors of production.

Table 2.4 details the sources of household factor income. Here, it is necessary to distinguish between endowment commodities that are perfectly mobile, and therefore earn the same market return (*ENDWM_COMM*), and those that are sluggish to adjust and that therefore sustain differential returns in equilibrium (*ENDWS_COMM*). In the former case, we may simply sum over all usage of the factor – since market prices are equal – thereupon deducting the tax on households' supply of primary factor *i* in region *s*, *HTAX(i,s)*, in order to obtain the *Value of this endowment's "Output" at Agents' prices* (*VOA*). The latter is the amount actually received by the private household supplying the factor in question.

In the case of the sluggish endowment commodities (e.g., land), shocks to the model will introduce differential price changes across sectors. This is reflected in the presence of an industry index (j), in the price component of $VFM(i,j,s)$. These differential prices are then combined into a composite return to the sluggish endowment, at market prices, via a unit revenue function. The resulting *Value of endowment Output at Market prices*, $VOM(i,s)$, is then handled in the same way as for mobile commodities, deducting household income taxes to arrive at the $VOA(i,s)$.

Disposition and sources of regional income

When taxes are present, the computation of disposable income for the regional household in Figures 2.1 and 2.2 becomes much more complex. At the top of Table 2.5, we have the condition that expenditures on private, government, and savings commodities must precisely exhaust regional income. This is followed by the expression that decomposes income by source. We begin by adding up endowment income (recall Figures 2.1 and 2.2). Note that all such income earned within a region accrues to households in that same region. From this, we must deduct depreciation expenses required to maintain the integrity of the initial capital stock, $VDEP(r)$, thereupon adding net tax receipts and rents associated with any quantitative restrictions.

Rather than keeping track of individual tax/subsidy flows in the model, the approach taken here is to compare the value of a given transaction, evaluated at agents', market, or world prices. If there is a discrepancy between what households receive for their labor supply and the value of this supply at market prices, then the difference must equal $HTAX(i,r)$, as shown in Table 2.4. Alternatively, this tax revenue could be rewritten in terms of an explicit *ad valorem* tax rate, $\tau(i,r)$, by noting that the household's supply price of endowment i is given by:

$$PS(i,r) = (1 - \tau(i,r))PM(i,r) = TO(i,r)PM(i,r),$$

where $TO(i,r)$ is referred to as the *power* of the *ad valorem* tax. Therefore:

$$\begin{aligned} VOM(i,r) - VOA(i,r) &= (1 - TO(i,r))PM(i,r)QO(i,r) \\ &= \tau(i,r)PM(i,r)QO(i,r). \end{aligned}$$

Thus, the fiscal implications of all tax/subsidy programs may be captured by comparison of the value of a given transaction at agents' versus market (or market versus world) prices. We assume that *taxes levied in region r always accrue to households in region r.*

The remaining terms in the income expression given in Table 2.5 account for all the other possible sources of tax revenues/subsidy expenditures in each

Table 2.5. *Disposition and Sources of Regional Income*

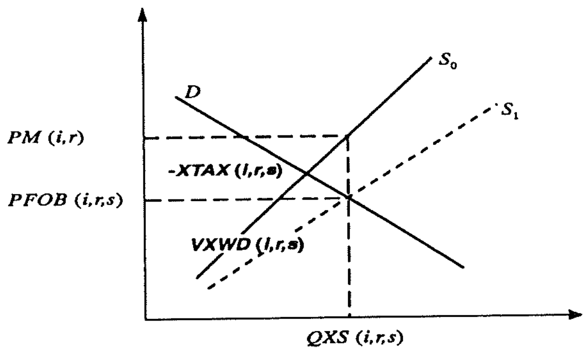
$$EXPENDITURE(r) = \sum_{i \in TRAD} [VPA(i,r) + VGA(i,r)] + SAVE(r) =$$

$$\begin{aligned}
INCOME\,(r) = \; & \sum_{i \in ENDW} VOA(i,r) - VDEP(r) \\
+ \; & \sum_{i \in NSAV} VOM(i,r) - VOA(i,r) \\
+ \; & \sum_{j \in PROD} \sum_{i \in ENDW} VFA(i,j,r) - VFM(i,j,r) \\
+ \; & \sum_{i \in TRAD} VIPA(i,r) - VIPM(i,r) \\
+ \; & \sum_{i \in TRAD} VDPA(i,r) - VDPM(i,r) \\
+ \; & \sum_{i \in TRAD} VIGA(i,r) - VIGM(i,r) \\
+ \; & \sum_{i \in TRAD} VDGA(i,r) - VDGM(i,r) \\
+ \; & \sum_{j \in PROD} \sum_{i \in TRAD} VIFA(i,j,r) - VIFM(i,j,r) \\
+ \; & \sum_{j \in PROD} \sum_{i \in TRAD} VDFA(i,j,r) - VDFM(i,j,r) \\
+ \; & \sum_{i \in TRAD} \sum_{s \in REG} VXWD(i,r,s) - VXMD(i,r,s) \\
+ \; & \sum_{i \in TRAD} \sum_{s \in REG} VIMS(i,s,r) - VIWS(i,s,r)
\end{aligned}$$

regional economy. These include: primary factor taxes on firms, commodity taxes on households', and firms' purchases of tradeable goods and trade taxes.[3]

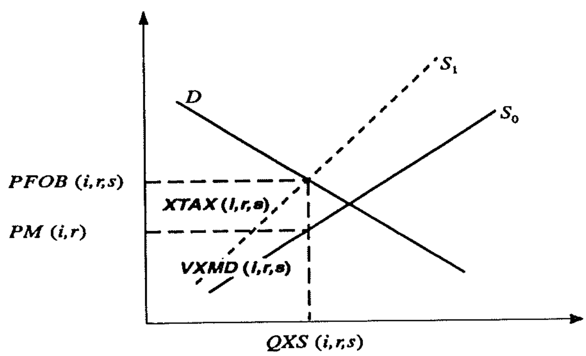
Figures 2.3 and 2.4, taken from Brockmeier (1996), offer graphical depictions of border interventions in GTAP. The two panels in Figure 2.3 refer to the case of export interventions. (Because there are many export destinations, we can interpret the supply curve as representing supply, net of sales to domestic uses, and other export markets.) In the first panel, the domestic price exceeds the world price ($PM(i,r) > PFOB(i,r,s)$), indicating the presence of a subsidy, so that $XTAX(i,r,s) = VXWD(i,r,s) - VXMD(i,r,s) < 0$. In the second panel, the opposite case is presented. Here, the world price is above the market

Export Subsidy



$$VXWD\ (i,r,s) = VXMD\ (i,r,s) - XTAX\ (i,r,s)$$

Export Tax

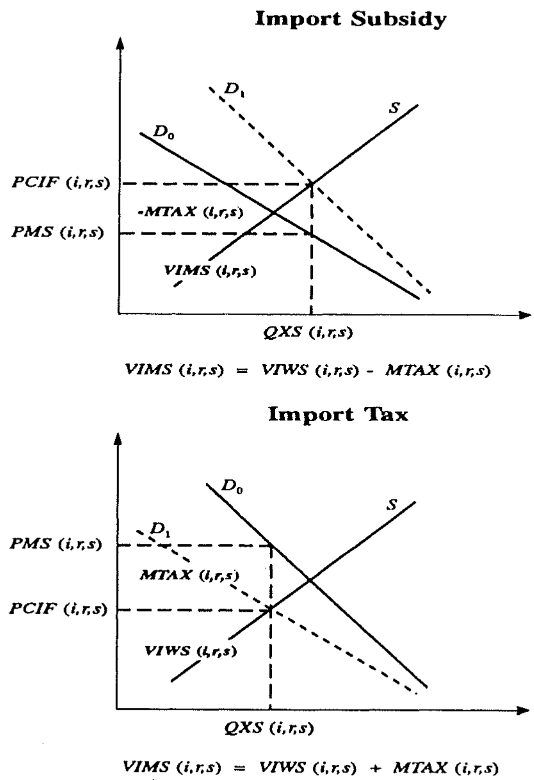


$$VXWD\ (i,r,s) = VXMD\ (i,r,s) + XTAX\ (i,r,s)$$

PM	Domestic price of commodity *i* in region *s* of origin *r*
PFOB	*FOB* price of commodity *i* supplied from region *r* to region *s*
QXS	Export of commodity *i* from region *r* to region *s*
VXMD	Exports of commodity *i* from region *r* to region *s*, valued at exporter's domestic price
VXWD	Exports of commodity *i* from region *r* to region *s*, valued at FOB price
XTAX	Tax revenues/Subsidy expenditures
D	Demand for imports of commodity *i* supplied from region *r* by region *s*
S_0	Pretax net supply of commodity *i* from region *r* in region *s*
S_1	Taxed net supply of commodity *i* from region *r* in region *s*,

where: $QXS(i,rs) = QO(i,r) - \sum_{k \neq s} QXS(i,r,k) - VST(i,r) =$ net supply of commodity *i* from region *r*

Figure 2.3. Export subsidy or tax in region *r* on sales to region *s*.



PMS	Importer's domestic price of commodity *i* supplied from region *r* to region *s*
PCIF	*CIF* price of commodity *i* supplied from region *r* to region *s*
QXS	Exports of commodity *i* from region *r* to region *s*
VIMS	Imports of commodity *i* from region *r* to region *s*, valued at importer's domestic price
VIWS	Imports of commodity *i* from region *r* to region *s*, valued at CIF price
MTAX	Tax revenues/Subsidy expenditures
D_0	Pretax demand for differentiated imports of commodity *i* from region *r* in regions
S_1	Net supply of commodity *i* from region *r* in region *s*

where: $QXS(i,rs) = QO(i,r) - \sum_{k \neq s} QXS(i,r,k) - VST(i,r) =$ net supply of commodity *i* from region *r*

Figure 2.4. Import subsidy or tax in region *s* on purchases from region *r*.

price and their difference contributes positively to regional income. This will be the case regardless of the source of discrepancy in *VXWD* and *VXMD*. For example, if this difference arises due to export restraints, as opposed to taxation, then the resulting income flow is due to quota rents. Nevertheless, it still accrues to the region of origin (r).

The two panels in Figure 2.4 refer to the income consequences of import interventions. Because GTAP adopts the Armington approach to import demand, differentiating products by origin, there is no domestic supply of the imported good. Therefore the demand schedule in these panels is conditional on aggregate demand for commodity i in region s, as well as the prices of competing imports and the domestic market price of i in region s. The excess supply schedule for imports of i from r to s depends on supply conditions in r as well as demand for this commodity in region s.

When the market price exceeds the world price, $PMS(i,r,s) > PCIF(i,r,s)$, then $MTAX(i,r,s) > 0$ and this term contributes positively to regional income. This can arise if there is a tariff on imports, *or* it could be due to an import quota. In the case of a binding quota on imports of i into s from r:

$$\begin{aligned} &VIMS(i,r,s) - VIWS(i,r,s) \\ &\quad = (TMS(i,r,s) - 1)PCIF(i,r,s)QXS(i,r,s) > 0 \end{aligned}$$

represents the associated quota rents. In this instance, the closure must be modified so that $QXS(i,r,s)$ is *exogenous* and the tax equivalent, $TMS(i,r,s)$, is *endogenous*. Again, these quota rents are assumed to accrue to the region administering the quota.

Global sectors

In order to complete the model, it is necessary to introduce two global sectors. The global transportation sector provides the services that account for the difference between *fob* and *cif* values for a particular commodity shipped along a specific route: $VTWR(i,r,s) = VIWS(i,r,s) - VXWD(i,r,s)$. Summing over all routes and commodities gives the total demand for international transport services shown at the top of Table 2.6. The supply of these services is provided by individual regional economies, which export them to the global transport sector [$VST(i,r)$]. We do not have information that would permit us to associate regional transport services exports with particular commodities and routes. Therefore, all demand is met from the same pool of services, the price of which is a blend of the price of all transport services exports.

The other required global sector is the global banking sector. This intermediates between global savings and investment, as described in Table 2.7. It creates a composite investment good (*GLOBINV*), based on a portfolio of net regional investment (gross investment less depreciation), and offers this to

Table 2.6. *The International Transport Sector*

	VT	$: PT * QT$
$= \sum_{i \in TRAD} \sum_{r \in REG} \sum_{s \in REG}$	$VTWR(i,r,s)$	$: PT * QS(i,rs)$
$= \sum_{i \in TRAD} \sum_{r \in REG}$	$VST(i,r)$	$: PM(i,r) * QST(i,r)$

Table 2.7. *Demand for Regional Investment Goods*

$\sum_{r \in REG} [REGINV(r)$	$: PCGDS(r) * QCGDS(r)$
$- \underline{VDEP(r)]}$	$: PCGDS(r) * KB(r)$
$= GLOBINV$	$: PSAVE * GLOBALCGDS$
$= \sum_{r \in REG} SAVE(r)$	$: PSAVE * QSAVE(r)$
Capital Stocks	
$VKB(r)$	$: PCGDS(r) * KB(r)$
$+ REGINV(r)$	$: PCGDS(r) * QCGDS(r)$
$- \underline{VDEP(r)}$	$: PCGDS(r) * DEPR(r) KB(r)$
$= VKE(r)$	

regional households in order to satisfy their savings demand. Therefore, all savers face a common price for this savings commodity (*PSAVE*). A consistency check on the accounting relationships described up to this point involves separately computing the supply of the composite investment good and the demand for aggregate savings. If (1) all other markets are in equilibrium,

(2) all firms earn zero profits (including the global transport sector), and (3) all households are on their budget constraint, then global investment must equal global savings by virtue of Walras' Law.

Finally, the value of the beginning of period capital stock, *VKB(r)*, is updated by regional investment, *REGINV(r)*, less depreciation, *VDEP(r)*. This yields the value of ending capital stocks, *VKE(r)*. This relationship is shown at the bottom of Table 2.7.

IV Equilibrium conditions and partial equilibrium closures

Thus far, we have said nothing about the behavior of individual firms and households. Neoclassical restrictions on such behavior are not necessary to obtain full general equilibrium closure. Rather, it is the exhaustive accounting relationships outlined above that make our model general equilibrium in nature. If any one of them is not enforced, Walras' Law will fail to hold. Since most economists are accustomed to seeing equilibrium conditions written in terms of quantities, not values, it is useful to demonstrate that the accounting relationships provided above do indeed embody the customary general equilibrium relationships. Consider, for example, the market clearing condition for tradeable commodity supplies:

$$VOM(i,r) = VDM(i,r) + VST(i,r) + \sum_{s \in REG} VXMD(i,r,s). \qquad (2.1)$$

This may be rewritten in terms of quantities and a common domestic market price for i in region r:

$$\begin{aligned} &PM(i,r) * QO(i,r) = \\ &PM(i,r) * [QDS(i,r) + QST(i,r) + \sum_{s \in REG} QXS(i,r,s)]. \end{aligned} \qquad (2.2)$$

Upon dividing by $PM(i,r)$ we obtain the usual form of the tradeable commodity market clearing condition:

$$QO(i,r) = QDS(i,r) + QST(i,r) + \sum_{s \in REG} QXS(i,r,s). \qquad (2.3)$$

A similar exercise may be applied to the market clearing conditions for nontradeable commodities. In sum, any market clearing condition can be converted to value terms by multiplying by a *common* price. In so doing, we circumvent the need to partition value flows into prices and quantities. This has the added benefit of vastly simplifying the problem of model calibration, as we will see below.

Having verified that the accounting relationships embody all the necessary general equilibrium conditions, we turn to the problem of creating special closures in which some of these conditions are dropped. This, in turn, permits one to fix certain variables exogenously, as is done *implicitly* in partial equilibrium analysis. The problem lies in ascertaining which variables are associated with which equilibrium conditions. This is akin to identifying the complementary slackness conditions associated with the general equilibrium model.

Perhaps the most obvious complementarity is that between prices and market clearing conditions. Clearly if the latter are to hold, prices must be free to adjust to resolve any imbalance between supply and demand. Therefore, if we fix the price of a tradeable commodity, we must eliminate the associated market clearing condition, equation (2.3). A common partial equilibrium closure for the analysis of farm and food issues involves fixing the prices of all nonfood commodities. In order to implement this closure in our model, all nonfood market clearing conditions must be dropped. (The "dropping" of individual equations is achieved by endogenizing slack variables in the equations to be eliminated. We must always retain equal numbers of endogenous variables and equations if the model is to provide a unique equilibrium solution.)

It is also common in partial equilibrium analyses to assume that the opportunity cost of nonspecific factors is exogenous. For example, in the case of agriculture, one might assume that the labor wage and capital rental rates are fixed. If this is to be done, then the associated regional market clearing conditions for these nontradeable primary factors must be dropped. Similarly, income may be fixed, provided the income computation equation is eliminated.

But what about quantities? Should any of them be fixed? Having fixed the price of nonfood commodities, for example, it hardly makes sense to permit their supplies to be determined endogenously. Any sector experiencing a rise in costs would be driven out of business altogether under such circumstances. For this reason it makes sense to fix nonfood output levels and drop the associated zero profit conditions. These partial equilibrium assumptions, for the example of a food policy shock, may be summarized as follows:

- *Nonfood output levels and prices are exogenous.*
- *Income is exogenous.*
- *Nonspecific primary factor rental rates are exogenous.*

V Linearized representation of accounting equations

Solution via a linearized representation. While the accounting relationships detailed in Figures 2.1 and 2.2 and Tables 2.1–2.5 are most conveniently expressed in value terms, it is attractive to write the behavioral component of the model in terms of *percentage changes* in prices and quantities.[4] Indeed, we are usually most interested in these percentage changes, as opposed to their levels values. Expressing this nonlinear model in percentage changes

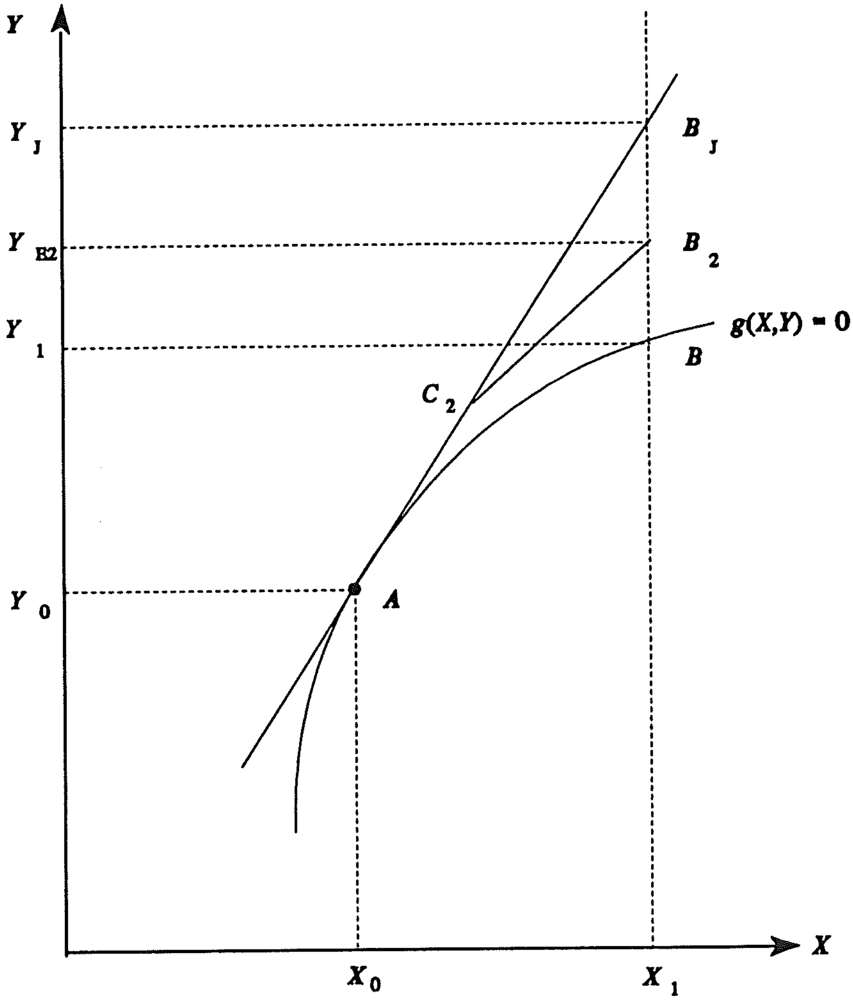


Figure 2.5. Solving a nonlinear model via its linearized representation.

does not preclude solution of the true nonlinear problem. Solution of nonlinear AGE models via a *linearized representation* (Pearson 1991)[5] involves successively updating the value-based coefficients via the formula:

$$dV/V = d(PQ)/PQ = p + q,$$

where the lowercase p and q denote proportional changes in price and quantity.

Figure 2.5 provides a graphical exposition of one method of solving a nonlinear model via its linearized representation. For simplicity, the entire model is given by a single equation $g(X,Y) = 0$, where X is exogenous and Y is endogenous. The initial equilibrium is represented by the point (X_0, Y_0). Our counterfactual experiment involves shocking the exogenous variable to X_1, and computing the resulting endogenous outcome Y_1. If we simply evaluated the linearized representation of the model at (X_0, Y_0) the equations would predict the outcome $B_J = (X_1, Y_J)$. This is the *Johansen approach*, and it is clearly in error, since $Y_J >> Y_1$. This type of error has led to criticism of the individuals using linearized computable general equilibrium (CGE) models.

However, note that the accuracy of the linearized model can be considerably enhanced by breaking the shock to X into two parts and updating the equilibrium after the first shock. This approach takes us from point A to C_2 to B_2. It is termed *Euler's method* of solution via linearized representation. By increasing the number of steps, one obtains an increasingly accurate solution of the nonlinear model.

Since Euler's contribution, this approach of relinearizing the model has been considerably refined to yield more rapid convergence to (X_1, Y_1). [See Harrison and Pearson (1994), section 2.5, for more details.] The default method used for solving the GTAP model is *Gragg's method*, with extrapolation. In this case the model is solved several times, each time with a successively finer grid. An extrapolated solution is formed based on these results. As illustrated in Harrison and Pearson (1994, pp. 2–24ff.), this yields good results.

Form of accounting equations. Linearization of the accounting equations involves total differentiation so they appear as a linear combination of appropriately weighted price and quantity changes. For example, the tradeable market clearing condition [equation (2.3)] becomes:

$$\begin{aligned} QO(i,r)qo(i,r) = {} & QDS(i,r)qds(i,r) + QST(i,r)qst(i,r) \\ & + \sum_{s\in REG} QXS(i,r,s)qxs(i,r,s), \end{aligned} \tag{2.4}$$

where the lowercase variables are again percentage changes. Multiplying both sides by the common price $PM(i,r)$ yields equation (1) in Table 2.8. Here the coefficients are now in *value* terms. [It is never necessary actually to compute price and quantity *levels* (P and Q) under this approach, although this can be done if one chooses to define initial units by choosing, for example, $PM(i,r) = 1$.] Also, note that a slack variable has been introduced into this equation in Table 2.8. It is indexed over all tradeable commodities and regions. By endogenizing selected components of this variable (which appear only in this equation), we are able to eliminate selectively market clearing for individual products. In this case, with the associated tradeable price fixed exogenously ($pm(i,r) = 0$), the endogenous change in *tradslack*(i,r) accounts for the excess

Table 2.8. *"Accounting" Relationships in the Model*

(1) $VOM(i,r) * qo(i,r) =$ $\quad \forall i \epsilon TRAD \; \forall r \epsilon REG$

$$VDM(i,r) * qds(i,r) + VST(i,r) * qst(i,r) + \sum_{s \epsilon REG} VXMD(i,r,s) * qxs(i,r,s) + VOM(i,r) * tradslack(i,r)$$

(2) $VIM(i,r) * qim(i,r) =$ $\quad \forall i \epsilon TRAD \; \forall r \epsilon REG$

$$\sum_{j \epsilon PROD} VIFM(i,j,r) * qfm(i,j,r) + VIPM(i,r) * qpm(i,r) + VIGM(i,r) * qgm(i,r)$$

(3) $VDM(i,r) * qds(i,r) =$ $\quad \forall i \epsilon TRAD \; \forall r \epsilon REG$

$$\sum_{j \epsilon PROD} VDFM(i,j,r) * qfd(i,j,r,) + VDPM(i,r) * qpd(i,r) + VDGM(i,r) * qgd(i,r)$$

(4) $VOM(i,r) * qo(i,r) =$ $\quad \forall i \epsilon ENDWM \; \forall r \epsilon REG$

$$\sum_{j \epsilon PROD} VFM(i,j,r) * qfe(i,j,r,) + VOM(i,r) * endwslack(i,r)$$

(5) $qoes(i,j,r) = qfe(i,j,r)$ $\quad \forall i \epsilon ENDWS \; \forall j \epsilon PROD \; \forall r \epsilon REG$

(6) $VOA(j,r) * ps(j,r) =$ $\quad \forall i \epsilon PROD \; \forall r \epsilon REG$

$$\sum_{i \epsilon ENDW} VFA(i,j,r) * pfe(i,j,r,) + \sum_{i \epsilon TRAD} VFA(i,j,r) * pf(i,j,r) + VOA(j,r) * profitslack(j,r)$$

(7) $VT * pt = \sum_{i \epsilon TRAD\_COMM} \sum_{r \epsilon REG} VST(i,r) * pm(i,r)$

(8) $PRIVEXP(r) * yp(r) =$ $\quad \forall r \epsilon REG$

$$INCOME(r) * y(r) - SAVE(r) * [psave + qsave(r)] - \sum_{i \epsilon TRAD} VGA(i,r) * [pg(i,r) + qg(i,r)]$$

of supply over demand in the new equilibrium (as a percentage of output in the initial equilibrium).

The next two equations in Table 2.8 enforce equilibrium in the *domestic market* for tradeable commodities, either that which is imported from region r in the case of equation (2) or that which is produced domestically in the case of equation (3). Therefore, the common price is once again a domestic market price. We do not include slack variables in these equations, since they refer to the same commodity treated in equation (1). To achieve a partial equilibrium closure, it is sufficient to fix the price of this good at one place in the model.

Table 2.8. *(Cont) "Accounting" Relationships in the Model*

(9) $$\begin{aligned} INCOME(r) * y(r) = {} & \sum_{i \in ENDW} VOA(i,r)[ps(i,r) + qo(i,r)] - VDEP(r) * [pcgds(r) + kb(r)] \\ & + \sum_{i \in NSAV} VOM(i,r) * [pm(i,r) + qo(i,r)] - VOA(i,r) * [ps(i,r) + qo(i,r)] \\ & + \sum_{i \in ENDWM} \sum_{j \in PROD} VFA(i,j,r)[pfe(i,j,r) + qfe(i,j,r)] - VFM(i,j,r) * [pm(i,r) + qfe(i,j,r)] \\ & + \sum_{j \in ENDWS} \sum_{i \in PROD} VFA(i,j,r)[pfe(i,j,r) + qfe(i,j,r)] - VFM(i,j,r) * [pmes(i,j,r) + qfe(i,j,r)] \\ & + \sum_{j \in PROD} \sum_{i \in TRAD} VIFA(i,j,r) * [pfm(i,j,r) + qfm(i,j,r)] - VIFM(i,j,r) * [pim(i,r) + qfm(i,j,r)] \\ & + \sum_{j \in PROD} \sum_{i \in TRAD} VDFA(i,j,r) * [pfd(i,j,r,) + qfd(i,j,r)] - VDFM(i,j,r) * [pm(i,r) + qfd(i,j,r)] \\ & + \sum_{i \in TRAD} VIPA(i,r) * [ppm(i,r) + qpm(i,r)] - VIPM(i,r) * [pim(i,r) + qpm(i,r)] \\ & + \sum_{i \in TRAD} VDPA(i,r) * [ppd(i,r) + qpd(i,r)] - VDPM(i,r) * [pm(i,r) + qpd(i,r)] \\ & + \sum_{i \in TRAD} VIGA(i,r) * [pgm(i,r) + qgm(i,r)] - VIGM(i,r) * [pim(i,r) + qgm(i,r)] \\ & + \sum_{i \in TRAD} VDGA(i,r) * [pgd(i,r) + qgd(i,r)] - VDGM(i,r) * [pm(i,r) + qgd(i,r)] \\ & + \sum_{i \in TRAD} \sum_{s \in REG} VXWD(i,r,s) * [pfob(i,r,s) + qxs(i,r,s)] - VXMD(i,r,s) * [pm(i,r) + qxs(i,r,s)] \\ & + \sum_{i \in TRAD} \sum_{s \in REG} VIMS(i,s,r) * [pms(i,s,r) + qxs(i,s,r)] - VIWS(i,s,r) * [pcif(i,s,r) + qxs(i,s,r)] \\ & + INCOME(r) * incomeslack(r) \end{aligned} \qquad \forall r \in REG$$

(10) $$ke(r) = INVKERATIO(r) * qcgds(r) + [1.0 - INVKERATIO(r)] * kb(r) \qquad \forall r \in REG$$

(11) $$globalcgds = \sum_{r \in REG} [REGINV(r)/GLOBINV] * qcgds(r) - [VDEP(r)/GLOBINV(r)] * kb(r)$$

(12) $$walras\_sup = globalcgds$$

(13) $$GLOBINV * walras\_dem = \sum_{r \in REG} SAVE(r) * qsave(r)$$

(14) $$walras\_sup = walras\_dem + walraslack$$

Equations (4) and (5) in Table 2.8 refer to market clearing for the nontradeable, endowment commodities. As noted above, the model distinguishes between primary factors that are perfectly mobile across sectors, and those which are "sluggish" in their adjustment. The latter class of endowment commodities can exhibit differential equilibrium rental rates across uses. In the case of mobile endowments, equation (4), the presence of a common market price permits the equilibrium relationship to be written in terms of values at domestic market prices. A slack variable is introduced to permit us selectively to eliminate the market clearing equations and fix rental rates on the respective endowment commodities. In the case of sluggish commodities, no such common price exists and sectoral demands are equated to sectoral supplies. The latter are generated from a constant elasticity of transformation (CET) revenue function, which transforms one use of the endowment into another.

Equation (6) in Table 2.8 is the zero pure profit condition. Since firms are assumed to maximize profits, the quantity changes drop out when the expression at the bottom of Table 2.3 is totally differentiated in the neighborhood of an optimum (e.g., Varian 1978, p. 267). This leaves an equation relating input prices to output prices, where these percentage changes are weighted by values at *agent's* prices. For computational convenience we use different variables to refer to firms' prices for composite intermediate inputs (*pf*) and endowment commodities (*pfe*). The presence of *profitslack(j,r)* permits us to fix output and eliminate the zero profit condition for any sector j in any region r. In a similar fashion, equation (7) is the zero profit condition for the international transport sector. Here, the total value of transport services (*VT*) is constrained to equal the total value of services exports to this sector/use (*VST*), as described in Table 2.6.

Equation (8) in Table 2.8 assures the complete disposition of regional income (recall Table 2.5). This is done by first deducting savings and government spending (each of which *may* be exogenously specified under some closures) from disposable regional income, thereupon allocating the remainder to private household expenditures *PRIVEXP(r)*. It is followed by equation (9), which generates available income in each region. This is the most complicated equation in the model. It must take account of changes in the value of regional endowments, as well as changes in the net fiscal revenues owing to the *ad valorem* taxes/subsidies. Even if these tax rates do not change, revenues will change due to changes in market prices and quantities. Therefore, in differential form, each of the values must be postmultiplied by the percentage change in both the price and quantity components of the value flow.

Note that in Table 2.8 the quantity change is common for each of the transactions taxes in equation (9). For example, in the case of the tax on firms' use of primary factors, the percentage change in firms' derived demands, *qfe(i,j,r)*, enters both terms. This is simply a reflection of the fact that the tax refers to a particular transaction in quantities. In contrast, the prices faced by firms are: (1) potentially different from market prices, and (2) free to change at different rates when the tax rate dividing them is changed. This is reflected by the fact that *VFA(i,j,r)* is postmultiplied by *pfe(i,j,r)*, while *VFM(i,j,r)* changes according to *pm(i,r)*.

Before going through Table 2.8 equation (9) in more detail it is useful to consider explicitly the taxes associated with each of these price differences. These are revealed in the price linkage equations given in Table 2.9; for example, equation (15) shows the role of income/output taxes that drive a wedge between *VOM(i,r)* and *VOA(i,r)*. The *power of the ad valorem tax* in this case is given by $TO(i,r) = VOA(i,r) / VOM(i,r)$. Therefore, when $TO(i,r) > 1$, firms/households are actually receiving a *subsidy* on the commodity supplied. Similarly, if $dTO(i,r) / TO(i,r) = to(i,r) > 0$ then the subsidy is increased. This choice of notation may seem odd, but it gives rise to a useful pattern across tax instruments. In particular, we adopt the rule that tax rates are always

Table 2.9. *Price Linkage Equations*

(15)	$ps(i,r) = to(i,r) + pm(i,r)$	$\forall i \in NSAVE$ $\forall r \in REG$
(16)	$pfe(i,j,r) = tf(i,j,r) + pm(i,r)$	$\forall i \in ENDWM$ $\forall j \in PROD$ $\forall r \in REG$
(17)	$pfe(i,j,r) = tf(i,j,r) + pmes(i,j,r)$	$\forall i \in ENDWS$ $\forall j \in PROD$ $\forall r \in REG$
(18)	$ppd(i,r) = tpd(i,r) + pm(i,r)$	$\forall i \in TRAD$ $\forall r \in REG$
(19)	$pgd(i,r) = tgd(i,r) + pm(i,r)$	$\forall i \in TRAD$ $\forall r \in REG$
(20)	$pfd(i,j,r) = tfd(i,j,r) + pm(i,r)$	$\forall i \in TRAD$ $\forall j \in PROD$ $\forall r \in REG$
(21)	$ppm(i,r) = tpm(i,r) + pim(i,r)$	$\forall i \in TRAD$ $\forall r \in REG$
(22)	$pgm(i,r) = tgm(i,r) + pim(i,r)$	$\forall i \in TRAD$ $\forall r \in REG$
(23)	$pfm(i,j,r) = tfm(i,j,r) + pim(i,r)$	$\forall i \in TRAD$ $\forall j \in PROD$ $\forall r \in REG$
(24)	$pms(i,r,s) = tm(i,s) + tms(i,r,s) + pcif(i,r,s)$	$\forall i \in TRAD$ $\forall r \in REG$ $\forall s \in REG$
(25)	$pr(i,s) = pm(i,s) - pim(i,s)$	$\forall i \in TRAD$ $\forall s \in REG$
(26)	$pcif(i,r,s) = FOBSHR(i,r,s) * pfob(i,r,s) + TRNSHR(i,r,s) * pt$	$\forall i \in TRAD$ $\forall r \in REG$ $\forall s \in REG$
(27)	$pfob(i,r,s) = pm(i,r) - tx(i,r) - txs(i,r,s)$	$\forall i \in TRAD$ $\forall r \in REG$ $\forall s \in REG$

defined as the ratio of agent's prices to market prices (or market prices to world prices in the case of border taxes).

Turning to the next price linkage relationship, equation (16) in Table 2.9, we note that an increase in $TF(i,j,r)$, that is, $tf(i,j,r) > 0$, will cause an *increase* in tax revenues. This is because in this case the firms in sector j of region r purchasing mobile endowment commodity i will be forced to pay more, relative to the market price, that is, $pfe(i,j,r) > pm(i,r)$. Owing to the fact that there is not a unique market price for the sluggish endowment commodities purchased by firms, we require a separate price linkage, equation (17) in this case.

Equations (18)–(20) in Table 2.9 describe the linkages between domestic market prices and agents purchasing *domestically produced*, tradeable commodities. These commodity transaction taxes can potentially vary not only across commodities and regions, but also across firms and households in each region. Similarly, equations (21)–(23) describe the linkage between the domestic market price of imports of *i*, by source *r*, and diverse agents in region *s*.

Equation (24) in Table 2.9 establishes the percentage change in the domestic market price for tradeable commodity *i* in region *s*, based on the change in the border price of that product, *pcif(i,r,s)* as well as two types of border interventions. Both are *ad valorem* import tariffs. The first, *tms(i,r,s)*, is bilateral in nature, while the second, *tm(i,s)*, is source-generic. The latter may be used to insulate the domestic economy from world price changes. This is done by endogenizing *tm(i,s)* and establishing some domestic price target. In this model, we choose to fix the ratio of the domestic market price for *i* to the price of the import composite. This is conveniently defined in the next price linkage, equation (25). In the normal closure, *tm(i,s)* is exogenous and *pr(i,s)* is endogenous. However, we imitate the European Union's variable import levy on food products by permitting *tm(i,s)* to vary so as to fix *pr(i,s)*. In this circumstance, domestic consumers have no incentive to substitute imports for domestic food.

Equation (26) in Table 2.9 links *pcif(i,r,s)* and *pfob(i,r,s)*. Its derivation is based on the assumption that revenues must cover costs on all *individual* routes, for all commodities. Thus the change in the *cif* price is a weighted combination of the change in the *fob* price and the change in a general transport cost index, *pt*, where the weights refer to the shares of *fob* costs [*FOBSHR(i,r,s)*] and transport costs [*TRNSHR(i,r,s)*] in *cif* costs. To the extent that firms engage in cross-subsidization or the costs of transport services on different routes move independently, this equation will be inaccurate. It is also important to note the implications of equation (26) for price transmission across markets. The greater the transport margin along a given route (i.e., *TRNSHR(i,r,s)* larger), the weaker the link between a change in the price of *i* in the export market *r* and the corresponding change in destination market *s*.

Equation (27) completes the "circle" of price linkages in Table 2.9 by connecting *pfob(i,r,s)* and domestic market price, *pm(i,r)*. As was the case on the import side, there are two types of export taxes. The first, *txs(i,r,s)*, is destination-specific, while the second, *tx(i,r)*, is destination-generic. The latter may be "swapped" with the normally endogenous change in sectoral output, in order to insulate domestic producers from the vagaries of world markets. For example, this variable export tax/subsidy has been used in modeling the European Union's (EU's) common agricultural policy. Note that since these export taxes refer to the ratio of domestic market prices to world prices, an increase in *TXS(i,r,s)* results in a fiscal outflow, that is, a subsidy on exports.

Having established the linkage between prices in this model, we are in a position to return to the income computation equation (9) in Table 2.8. In particular, consider the effect of omitting some component of this complicated equation, say, income taxes. How will this affect, for example, a welfare analysis of trade policy reform? Given the presence of income taxes in the initial equilibrium data base, $VOM(i,r) > VOA(i,r)$, if the experiment in question does not alter the *rate* of income taxation, then $to(i,r) = 0$ and $\alpha = ps(i,r) = pm(i,r)\ \forall i \varepsilon ENDW$. This means the two terms in square brackets [*] change at the same rate. If this change is positive, then omission of this term will lead to an *understatement* of income tax revenues and a subsequent *understatement* of disposable income and household welfare in the new equilibrium. In sum, even when distortions are not affected by a given policy experiment it is important to acknowledge their presence in the economy if an accurate welfare analysis is to be provided.

The final group of accounting equations in Table 2.8 refer to global savings and investment. Because this is a comparative static model, current investment does not augment the productive stock of capital available to firms. The latter is constrained by beginning-of-period capital stock which is exogenous. Therefore, there is only a limited role for investment in our simulations. When investment (and savings) is specified exogenously it will facilitate accumulation of the targeted end-of-period capital stock [see equation (10)]. When investment is endogenous it adjusts in order to accommodate the global demand for savings. (More discussion of these macroeconomic closure issues is provided below.) Equation (11) aggregates regional *gross* investment into global net investment. Equation (13) aggregates regional savings, and equations (12) and (14) permit us either to force the two to be equal (*walraslack* is exogenous) or verify Walras' Law (*walraslack* is endogenous and should be found equal to zero in the solution).

VI Behavioral equations

Firm Behavior

The "technology tree." Figure 2.6 provides a visual display of the assumed technology for firms in each of the industries in the model. This kind of a production "tree" is a convenient way of representing separable, constant returns-to-scale technologies. At the bottom of the inverted tree are the individual inputs demanded by the firm. For example, the primary factors of production are: land, labor, and capital. Their quantities are denoted *QFE(i,j,s)*, or,

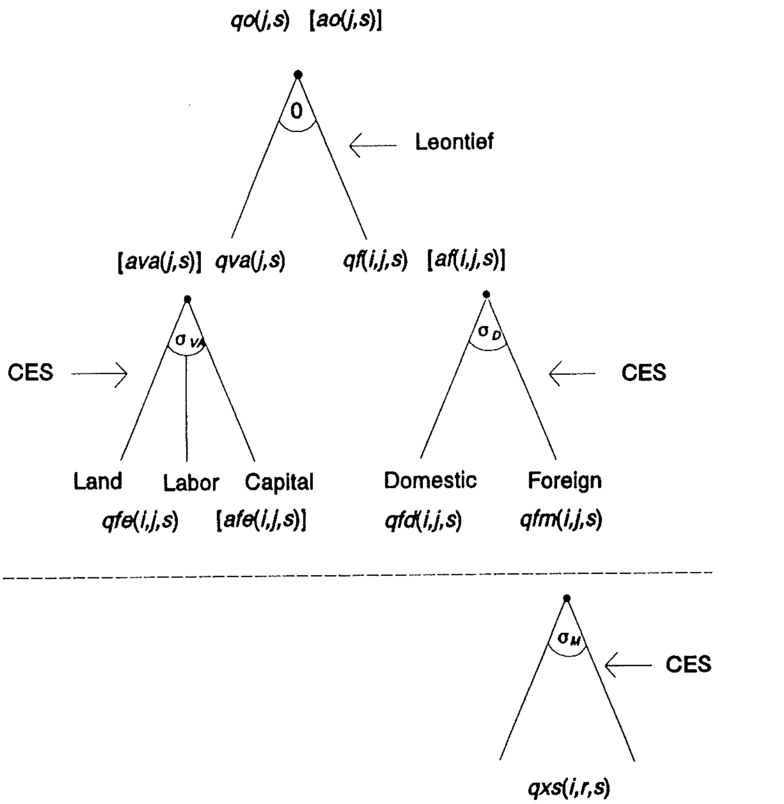


Figure 2.6. Production structure.

in percentage change form, *qfe(i,j,s)*. (For the time being, please ignore the terms in brackets [ ] in Figure 2.6. They refer to rates of technical change, to which we will turn momentarily.) Firms also purchase intermediate inputs, some of which are produced domestically, *qfd(i,j,s)*, and some of which are imported, *qfm(i,j,s)*. In the case of imports, the intermediate inputs must be "sourced" from particular exporters, *qxs(i,r,s)*. Recall from Figure 2.1 that this sourcing occurs at the border, since information on the composition of imports by sector is unavailable; hence the dashed line between the firms' production tree and the *constant elasticity of substitution* (CES) nest combining bilateral imports.

The manner in which the firm combines individual inputs to produce its output, *QO(i,s)*, depends largely on the assumptions that we make about *separability* in production. For example, we assume that firms choose their optimal mix of primary factors *independently* of the prices of intermediate inputs. Since the level of output is also irrelevant, owing to our assumption of constant returns to scale, this leaves only the relative prices of land, labor, and capital as arguments in the firms' conditional demand equations for components of value-added. By assuming this type of separability, we impose the restriction that the elasticity of substitution between any individual primary factor, on the one hand, and intermediate inputs, on the other, is equal. This is what permits us to draw the production tree, for it is this common elasticity of substitution that enters the fork in the inverted tree at which the intermediate and primary factors of production are joined. It also represents a significant reduction in the number of parameters that need to be provided in order to operationalize the model.

Within the primary factor branch of the production tree, substitution possibilities are also restricted to one parameter. This CES assumption is quite general in those sectors that employ only two inputs: capital and labor. However, in agriculture, where a third input, land, enters the production function, we are forced to assume that all pairwise elasticities of substitution are equal. This is surely not true, but we do not have enough information to calibrate a more general specification at this point.

In general, the behavioral parameters at each level in the production tree can be specified by the user of the model. However, as will be seen below when we turn to the specific form of the equations used to represent firm behavior, we impose the restriction of nonsubstitution between composite intermediates and primary factors. The fact that this is a very common specification in applied general equilibrium (AGE) models is a poor justification for incorporating it into the GTAP model. Indeed, there is evidence of significant substitutability between some intermediate inputs and primary factors. For example, during the energy price shocks of the 1970s firms demonstrated considerable potential for conserving fuel via the purchase of new, more energy-efficient equipment. Similarly, farmers have shown considerable potential for altering the rate of chemical fertilizer applications in response to changes in the relative price of fertilizer to land. However, these substitution possibilities are not characteristic of *all* intermediate inputs, and their proper treatment requires a more flexible production function than that portrayed in Figure 2.6.[6]

Turning to the intermediate input side of the production tree in Figure 2.6, it can be seen that the separability is symmetric, that is, the mix of intermediate inputs is also independent of the prices of primary factors. Furthermore, imported intermediates are assumed to be separable from domestically produced intermediate inputs. That is, firms first decide on the sourcing of their imports; then, based on the resulting composite import price, they determine the optimal mix of imported and domestic goods. This specification was first proposed by Paul Armington in 1969 and has since become known as the "Armington approach" to modeling import demand. However, it has been widely criticized in the literature. For example, Winters (1984), and Alston et al. (1990) argue that the functional form is too restrictive and that the nonhomothetic, AIDS specification is preferable. Although we agree that more flexible functional forms are preferable, this critique could apply just as well to every other behavioral relationship in the model. The question is: can it be estimated/calibrated and operationalized in the context of a disaggregated global model? At this point the answer is "no," although progress has been made in the context of one-region models (e.g., Robinson et al. 1993).

A more fundamental critique of the Armington approach is provided by the literature on industrial organization, imperfect competition, and trade. Here, product differentiation is *endogenous* and it is associated with individual firms' attempts to carve out a market niche for themselves. Early work along these lines is offered by Spence (1976), and Dixit and Stiglitz (1979). It is now the preferred approach for introducing imperfect competition into AGE models (e.g., Brown and Stern 1989), and it can have significant implications for the effects of trade policy liberalization (Hertel and Lanclos 1994). Also, Feenstra (1994) shows that the failure to account for endogenous product differentiation may be part of the reason import demands appear to be nonhomothetic. This is due to the correlation of income increases with the entry of new exporters and the subsequent increase in import varieties. Even at constant prices, this would dictate an increasing market share for imports.

In sum, although we are not particularly happy with the Armington specification, it *does* permit us to explain cross-hauling of similar products and to track bilateral trade flows. We believe that, in many sectors, an imperfect competition/endogenous product differentiation approach would be preferable. However, those models require additional information on industry concentration (firm numbers) as well as scale economies (or fixed costs), which is not readily available on a global basis. Clearly this is an important area for future work. Indeed, a number of authors have used aggregated versions of the GTAP data base to implement models with imperfect competition (Harrison, Rutherford, and Tarr 1995; Hertel and Lanclos 1994, Francois, McDonald, and Nordstrom 1995).

Behavioral equations. The equations describing the firm behavior portrayed in Figure 2.6 are provided in Tables 2.10 and 2.11. Each group of equations refers to one of the "nests" or branches in the technology tree discussed above. For each nest there are two types of equations. The first describes substitution among inputs within the nest. Its form follows directly from the CES form of the production function for that branch. (Details are provided later in this

Table 2.10. *Composite Imports Nest*

$$(28)\ pim(i,s) = \sum_{k \in REG} MSHRS(i,k,s) * pms(i,k,s) \qquad \forall i \in TRAD,\ \forall s \in REG$$

$$(29)\ qxs(i,r,s) = qim(i,s) - \sigma_M(i) * [pms(i,r,s) - pim(i,s)] \qquad \forall i \in TRAD,\ \forall r \in REG,\ \forall s \in REG$$

Table 2.11. *Behavioral Equations for Producers*

Composite intermediates nest:

$$(30)\ pf(i,j,r) = FMSHR(i,j,r) * pfm(i,j,r) + [1 - FMSHR(i,j,r)] * pfd(i,j,r) \qquad \forall i \in TRAD,\ \forall j \in PROD,\ \forall r \in REG$$

$$(31)\ qfm(i,j,s) = qf(i,j,s) - \sigma_D(i) * [pfm(i,j,s) - pf(i,j,s)] \qquad \forall i \in TRAD,\ \forall j \in PROD,\ \forall s \in REG$$

$$(32)\ qfd(i,j,s) = qf(i,j,s) - \sigma_D(i) * [pfd(i,j,s) - pf(i,j,s)] \qquad \forall i \in TRAD,\ \forall j \in PROD,\ \forall s \in REG$$

Value-added nest:

$$(33)\ pva(j,r) = \sum_{k \in ENDW} SVA(k,j,r) * [pfe(k,j,r) - afe\ k,j,r)] \qquad \forall j \in PROD,\ \forall r \in REG$$

$$(34)\ qfe(i,j,r) + afe\ (i,j,r) = qva(j,r) - \sigma_{VA}(j) * [pfe(i,j,r) - afe(i,j,r) - pva(j,r)] \qquad \forall i \in ENDW,\ \forall j \in PROD,\ \forall r \in REG$$

Total output nest:

$$(35)\ qva(j,r) + ava\ (j,r) = qo(j,r) - ao(j,r) \qquad \forall j \in PROD,\ \forall r \in REG$$

$$(36)\ qf(i,j,r) + af\ (i,j,r) = qo(j,r) - ao(j,r) \qquad \forall i \in TRAD,\ \forall j \in PROD,\ \forall r \in REG$$

Zero profits (revised):

$$(6')\ VOA(j,r) * [ps(j,r) + ao(j,r)] = \sum_{i \in ENDW\_COMM} VFA(i,j,r) * [pfe(i,j,r) - afe(i,j,r) - ava(j,r)] + \sum_{i \in TRAD\_COMM} VFA(i,j,r) * [pf(i,j,r) - af(i,j,r)] + VOA(j,r) * profitslack(j,r) \qquad \forall j \in PROD,\ \forall r \in REG$$

section.) The second type of equation is the composite price equation that determines the unit cost for the composite good produced by that branch (e.g., composite imports). (It takes the same form as the sectoral zero profit condition given in Table 2.8.) The composite price then enters the next higher nest in order to determine the demand for this composite.

There are several approaches to obtaining the CES-derived demand equations. Here, we opt for an intuitive exposition that begins with the definition of the elasticity of substitution. Indeed, this is the way the CES functional form was invented (Arrow et al. 1961). Consider the two input-case, where the elasticity of substitution is defined as the percentage change in the ratio of the two cost minimizing input demands, given a 1 percent change in the inverse of their price ratio:

$$\sigma \equiv (Q_1 \hat{/} Q_2)/(P_2 \hat{/} P_1). \tag{2.5}$$

(Here, the "hats" denote percentage changes.) A familiar benchmark is the Cobb–Douglas case, whereby σ equals 1. In this case cost shares are invariant to price changes. For larger values of σ, the rate of change in the quantity ratio exceeds the rate of change in the price ratio and the cost share of the input that becomes more expensive actually falls. Expressing equation (2.5) in percentage change form (lowercase letters), we obtain:

$$(q_1 - q_2) = \sigma(p_2 - p_1). \tag{2.6}$$

In order to obtain the form of demand equation used in Table 2.10, several substitutions are necessary. First, note that total differentiation of the production function, and use of the fact that firms' pay factors their marginal value product, gives the following relationship between inputs and output (i.e., the composite good):

$$q = \theta_1 q_1 + (1 - \theta_1) q_2, \tag{2.7}$$

where θ_1 is the cost share of input 1 and $(1 - \theta_1)$ is the cost share of input 2. Solving for q_2 gives:

$$q_2 = (q - \theta_1 q_1)/(1 - \theta_1), \tag{2.8}$$

which may be substituted into (2.6) to yield:

$$q_1 = \sigma(p_2 - p_1) + [q - \theta_1 q_1]/(1 - \theta_1). \tag{2.9}$$

This simplifies to the following derived demand equation for the first input:

$$q_1 = (1 - \theta_1)\sigma(p_2 - p_1) + q. \tag{2.10}$$

Note that this conditional demand equation is homogeneous of degree zero in prices, and the compensated cross-price elasticity of demand is equal to $(1 - \theta_1) * \sigma$.

The final substitution required to obtain the CES demand equation introduces the percentage change in the composite price:

$$p = \theta_1 p_1 + (1 - \theta_1)p_2. \tag{2.11}$$

As noted above, this is identical to the zero profit condition (6) in Table 2.8, only we have divided both sides by the value of output at agents' prices. Since revenue is exhausted on costs, the resulting coefficients weighting input prices are the respective cost shares. From here, we proceed in an manner analogous to that explored above, first solving for p_2 as a function of p_1 and p, then substituting this into (2.10) to obtain:

$$q_1 = (1 - \theta_1)\sigma\{[p - \theta_1 p_1]/(1 - \theta_1) - p_1\} + q. \tag{2.12}$$

This simplifies to the following, final form of the derived demand equation for the first input in this CES composite:

$$q_1 = \sigma(p - p_1) + q. \tag{2.13}$$

The beauty of equation (2.13) is the intuition it offers, and the fact that *its form is unchanged when the number of inputs increases beyond two.* This equation decomposes the change in a firm's derived demand, q_1, into two parts. The first is the substitution effect. It is the product of the (constant) elasticity of substitution and the percentage change in the ratio of the composite price to the price of input 1. The second component is the expansion effect. Owing to constant returns to scale, this is simply an equiproportionate relationship between output and input.

We are now in a position to return to Tables 2.10 and 2.11 and consider the individual equations more closely. As noted above, each CES "nest" in Figure 2.6 contains two types of equations: a composite price equation and the set of conditional demand equations. For example, equation (28), at the top of Table 2.10, explains the percentage change in the composite price of imports *pim(i,s)*. In contrast to the sectoral price equation (6) in Table 2.8, we use a cost share, *MSHRS(i,k,s)* which is the share of imports of i from region k in the composite imports of i in region s (recall that this composite is the same for all uses in the region). The next equation determines the sourcing of imports, according to their individual market prices, *pms(i,r,s)*, relative to the price of composite imports, *pim(i,s)*.

The first set of equations in Table 2.11 describes the composite intermediate inputs nest. This is specific to the individual sector in question. Here, *FMSHR(i,j,r)* refers to the share of imports in firms' composite tradeable commodity i in sector j of region r. Note that our choice of notation requires separate conditional demand equations for imported [equation (31)] and domestic [equation (32)] goods. Otherwise, the structure of these demands follows the usual format.

Equations (33) and (34) in Table 2.11 describe the value-added nest of the producers' technology tree. In particular, they explain changes in the price of composite value-added (*pva*) and the conditional demands (*qfe*) for endowment commodities in each sector. Here, the coefficient *SVA(i,j,r)* refers to the share of endowment commodity *i* in the total cost of value-added in sector *j* of *r*. In addition to the price variables, *pfe(i,j,r)*, these equations include variables governing the rate of primary factor-augmenting technical change, *afe(i,j,r)*. More specifically, this is the rate of change in the variable *AFE(i,j,r)*, where *AFE(i,j,r)*QFE(i,j,r)* equals the *effective* input of primary factor *i* in sector *j* of region *r*. Therefore, a value of $afe(i,j,r) > 0$ results in a decline in the effective price of primary factor *i*. For this reason it enters the equations as a deduction from *pfe(i,j,r)*. This has the effect of: (1) encouraging substitution of factor *i* for other primary inputs via the right-hand side of equation (34), (2) diminishing the demand (at constant effective prices) for *i* via the left-hand side of equation (34), and (3) lowering the cost of the value-added composite via equation (33) – thereby encouraging an expansion in the use of all primary factors.

Finally, we have the top-level nest, which generates the demand for composite value-added and intermediate inputs. Since we have assumed no substitutability between intermediates and value-added, the relative price component of these conditional demands drops out, and we are left with only the expansion effect. Furthermore, there are three types of technical change introduced in this nest. The variables *ava(j,r)* and *af(i,j,r)* refer to input augmenting technical-change in composite value-added and intermediates, respectively. The variable *ao(j,r)* refers to Hicks-neutral technical change. It uniformly reduces the input requirements associated with producing a given level of output. Finally, we have restated the zero profits condition (6'), which serves to determine the price of output in this sector. This revised equation reflects the effect of technical change on the composite output price for commodity *j* produced in region *r*.

Implications for tariff reform. At this point it is useful to employ the linearized representation of producer behavior provided in Table 2.11 to think through the effects of a trade policy shock. Consider, for example, a reduction of the bilateral tariff on imports of *i* from *r* into s, *tms(i,r,s)*. This lowers *pms(i,r,s)* via price linkage equation (24) in Table 2.9. Domestic users immediately substitute away from competing imports according to equation (29) in Table 2.10. Also, the composite price of imports facing sector *j* falls via equations (28) and (23), thereby increasing the aggregate demand for imports through equation (31) in Table 2.11. Cheaper imports serve to lower the composite price of intermediates through equation (30), which causes excess profits at current prices, via equation (6). This in turn induces output to expand, which in turn generates an expansion effect via equations (35) and (36) in Table 2.11. (Of course, in a partial equilibrium model whereby nonfood sectors' activity levels are exogenous, the latter effect will be present only when *j* refers to a food sector.)

The expansion effect induces increased demands for primary factors of production via equation (34) in Table 2.11. In a partial equilibrium closure, labor and capital might be assumed forthcoming in perfectly elastic supply from the nonfood sectors, so $pfe(i,j,r)$ is unchanged for i = labor, capital. However, in the general equilibrium model, this expansion generates an excess demand via the mobile endowment market clearing condition equation (4), thereby bidding up the prices of these factors, and transmitting the shock to other sectors in the liberalizing region.

Now turn to region r, which produces the goods for which $tms(i,r,s)$ is reduced. Equation (29) in Table 2.10 may be used to determine the implications for total sales of i from r to s, given the responses of agents in region s to the tariff shock. Equation (1) dictates the subsequent implications for total output: $qo(i,r)$ (unless this market clearing condition has been eliminated, and $pm(i,r)$ fixed, under a particular PE closure). At this point, the equations in Table 2.11 again come into play, with equations (35) and (36) transmitting the expansion effect back to intermediate demands and to region r's factor markets.

Household behavior

Theory. As shown in Figures 2.1 and 2.2, regional household behavior is governed by an aggregate utility function, specified over composite private consumption, composite government purchases, and savings. The motivation for including savings in this static utility function derives from the work of Howe (1975), who showed that the intertemporal, extended linear expenditure system (ELES) could be derived from an equivalent, atemporal maximization problem, in which savings enters the utility function. Specifically, he begins with a Stone–Geary utility function, thereupon imposing the restriction that the subsistence budget share for savings is zero. This gives rise to a set of expenditure equations for current consumption that are equivalent to those flowing from Lluch's (1973) intertemporal optimization problem.[7] In the GTAP model we employ a special case of the Stone–Geary utility function, whereby *all* subsistence shares are equal to zero. Therefore, Howe's result, linking this specification with a well-defined intertemporal maximization problem, is applicable.

The other feature of our regional household utility function requiring some explanation is the use of an index of current government expenditure to proxy the welfare derived from the government's provision of public goods and

Table 2.12. *Household Behavior*

Aggregate utility

(37) $INCOME(r) * u(r) = PRIVEXP(r) * up(r) + GOVEXP(r) * [ug(r) - pop(r)] + SAVE(r) * [qsave(r) - pop(r)]$ $\forall r \in REG$

Regional savings:

(38) $qsave(r) = y(r) - psave + saveslack(r)$ $\forall r \in REG$

Government purchases:

(39) $ug(r) = y(r) - pgov(r) + govslack(r)$ $\forall r \in REG$

Demand for composite goods:

(40) $pgov(r) = \sum_{i \in TRAD\_COMM} (VGA(i,r)/GOVEXP(r)) * pg(i,r)$ $\forall r \in REG$

(41) $qg(i,r) = ug(r) - [pg(i,r) - pgov(r)]$ $\forall i \in TRAD$ $\forall r \in REG$

Composite tradeables:

(42) $pg(i,s) = GMSHR(i,s) * pgm(i,s) + [1 - GMSHR(i,s)] * pgd(i,s)$ $\forall i \in TRAD$ $\forall s \in REG$

(43) $qgm(i,s) = qg(i,s) + \sigma_D(i) * [pg(i,s) - pgm(i,s)]$ $\forall i \in TRAD$ $\forall s \in REG$

(44) $qgd(i,s) = qg(i,s) + \sigma_D(i) * [pg(i,s) - pgd(i,s)]$ $\forall i \in TRAD$ $\forall s \in REG$

services to private households in the region. Here, we draw on the work of Keller (1980, chap. 8), who demonstrates that if (1) preferences for public goods are separable from preferences for private goods, and (2) the utility function for public goods is identical across households within the regional economy, then we can derive a public utility function. The aggregation of this index with private utility in order to make inferences about regional welfare requires the further assumption that the level of public goods provided in the initial equilibrium is optimal. Users who do not wish to invoke this assumption can fix the level of aggregate government utility, letting private consumption adjust accordingly.

Equations. The behavioral equations for regional households in the model are laid out in Table 2.12. As previously noted, this household disposes of total regional income according to a Cobb–Douglas per capita utility function specified over the three forms of final demand: private household expenditures, government expenditures, and savings [equation (37)]. Thus in the standard closure, the claims of each of these areas represent a constant share of total income. This may be seen from equations (38) and (39), which determine the

Table 2.12. *(Cont) Household Behavior*

Private Household demands:

(45) $yp(r) = \sum_{i \in TRAD} [CONSHR(i,r) * pp(i,r)]$ $+ \sum_{i \in TRAD} [CONSHR(i,r) * INCPAR(i,r)] * up(r)$ $+ pop(r)$	$\forall r \in REG$
Composite demands:	
(46) $qp(i,r) = \sum_{k \in TRAD} EP(i,k,r) * pp(k,r) + EY(i,r) * [yp(r) - pop(r)] + pop(r)$	$\forall i \in TRAD$ $\forall r \in REG$
Composite tradeables:	
(47) $pp(i,s) = PMSHR,(i,s) * ppm(i,s) + [1 - PMSHR(i,s)] * ppd(i,s)$	$\forall i \in TRAD$ $\forall s \in REG$
(48) $qpd(i,s) = qp(i,s) + \sigma_D(i,) * [pp(i,s) - ppd(i,s)]$	$\forall i \in TRAD$ $\forall s \in REG$
(49) $qpm(i,s) = qp(i,s) + \sigma_D(i) * [pp(i,s) - ppm(i,s)]$	$\forall i \in TRAD$ $\forall s \in REG$

changes in real expenditures on savings and government activities as a function of regional income and prices. These equations also include slack variables that may be swapped with the quantities of savings and government composites, *qsave* and *ug*, if the user wishes to specify the latter variables exogenously. In order to assure the exhaustion of total regional income under these closures, equation (8) computes the change in private household spending as a residual. Both private and government demands are composite goods that require further elaboration. We turn first to the disaggregate government demands.

Government demands. Once the percentage change in real government spending has been determined, the next task is to allocate this spending across composite goods. Here, the Cobb–Douglas assumption of constant budget shares is once again applied. This is implemented via equations (40) and (41) in Table 2.12. In the first of these equations an aggregate price index for all government purchases, *pgov(r)*, is established. This in turn provides the basis for deriving the conditional demands for composite tradeable goods, *qg(i,r)*. Note the similarity between equation (41) and the CES production nests in Table 2.11. [Since we restrict the elasticity of substitution among composite products in the government's utility function to be unitary, this parameter does not appear in equation (41).]

Once aggregate demand for the composite is established, the remainder of the government's utility "tree" is completely analogous to that of the firms represented in Figure 2.6 and Table 2.11. First, a price index is established, equation (42), then composite demand is allocated between imports and domestically produced goods. Finally, the sourcing of imports occurs at the border, via the equations in Table 2.10. Due to the lack of use-specific Armington substitution parameters, σ_D is also assumed to be equal across all uses, that is, across all firms and households. Therefore, the only thing that distinguishes firms' and households' import demands are the differing import shares. However, this is not an insignificant difference. Some sectors/households are more intensive in their use of imports. Consequently, they will be more directly affected by a change in, for example, a tariff on the imported goods. This is why the effort expended to establish the detailed mapping of imports to sectors is warranted.

Private demands. The nonhomothetic nature of private household demands necessitates a somewhat different treatment. First of all, the computation of the utility of private household consumption must now take explicit account of the rate of population growth. Therefore the percentage change in private utility, *up*(*r*), is defined on a per capita basis. The particular method for calculating the percentage change in the utility of private consumption is dictated by the assumed form of private household preferences. For practical reasons, we have chosen to employ the constant difference of elasticities (CDE) functional form, first proposed by Hanoch (1975). It lies midway between the nonhomothetic CES on the one hand, and the fully flexible functional forms on the other. For our purposes, its main virtue is the ease with which it may be calibrated to existing information on income and own-price elasticities of demand. (For an exhaustive treatment of the calibration and use of the CDE functional form in AGE models, see Hertel et al. 1991.)

The CDE implicit expenditure function is given by (2.14):

$$\sum_{i \epsilon TRAD} B(i,r) * UP(r)^{\beta(i,r)\gamma(i,r)} * [PP(i,r)/E(PP(r),UP(r))]^{\beta(i,r)} \equiv 1. \quad (2.14)$$

Here, $E(\cdot)$ represents the minimum expenditure required to attain a prespecified level of private household utility, $UP(r)$, given the vector of private household prices, $PP(r)$. Minimum expenditure is used to normalize individual prices. These scaled prices are then raised to the power $\beta(i,r)$ and combined in an *additive* form. Unless β is common across all commodities in a given region, minimum expenditure cannot be factored out of the left-hand side expression and (2.14) is an *implicitly additive* expenditure function. The calibration problem involves choosing the values of β to replicate the desired compensated, own-price elasticities of demand, then choosing the γ's to replicate the targeted income elasticities of demand. (The shift term $B(i,r)$ is a scale factor embodied in the budget share, CONSHR(i,r), in the linearized representation of these preferences.)

Total differentiation of (2.14) and use of Shephard's lemma permits us to derive the relationship between minimum expenditure, utility, and prices that is given in equation (45) of Table 2.12 (see also Hertel, Horridge, and Pearson 1992). Equation (46) determines per capita private household demands for the tradeable composite commodities: $qp(i,r) - pop(r)$. As long as $EY(i,r)$ departs from unity, the $pop(r)$ term does not cancel out, as it did in the case of homothetic government and savings demands. Finally, in Table 2.12 we have a block of equations that develop the mix of composite consumption of tradeable commodities, based on domestic and composite imported goods.

As noted in the previous paragraph, the parameters of the CDE function are initially selected (i.e., calibrated) to replicate a prespecified vector of own-price and income elasticities of demand. However, with the exception of some special cases of the CDE (e.g., the Cobb–Douglas), these elasticities are not constants. Rather, they vary with expenditure shares/relative prices. [See Hertel et al. (1991) for derivations and more detailed discussion of these formulas. Chapter 4 also provides illustrations of how the income elasticities of demand vary over expenditure levels.] For this reason we need some supplementary formulas describing how the elasticities are updated with each iteration of the nonlinear solution procedure.

The formulas for the uncompensated price and income elasticities of demand, $EP(i,k,r)$ and $EY(i,r)$, are reported in Table 2.13. (These are not assigned equation numbers, as they are merely used to compute parameter values to be used in the system of equations representing the model. Therefore, they are given the prefix "F.") The first of these simply defines a parameter, α, that is equal to one minus the CDE substitution parameter. (This simplifies some of the other formulas.) Formulas (F2) and (F3) compute the own- and cross-price Allen partial elasticities of substitution in consumption. (The latter are symmetric.) These are simply a function of α and the consumption shares. It may be seen that when $\beta(i,r) = \beta\ \forall i$, then the cross-price elasticities of substitution are all equal to $1 - \beta = \alpha$ and the CDE simplifies to a CES function. Furthermore, when $\beta = 1$, there is no substitution in consumption and when $\beta = 0$, preferences are Cobb–Douglas. When premultiplied by $CONSHR(i,r)$, formula (F3) yields the compensated, own-price elasticity of demand for commodity i. Once these have been specified, this linear system of equations may be solved for the "calibrated" values of α, and hence β, via (F1). (See Chapter 4 for a more extensive discussion of calibration procedures.)

Formula (F4) shows how the income elasticities of demand are computed as a function of consumption shares, the income expansion parameters, γ's, and the α's. Because of this, calibration of the own-price elasticities of demand

Table 2.13. *Formulas for Private Households' Elasticities of Demand in the Presence of CDE Preferences*

(F1) $\alpha(i,r) = [1 - \beta(i,r)]$	$\forall i \epsilon TRAD$ $\forall r \epsilon REG$
(F2) $APE(i,k,r) = \alpha(i,r) + \alpha(k,r) - \sum_{m \epsilon TRAD} [CONSHR(m,r) * \alpha(m,r)]$	$\forall i \neq k \epsilon TRAD$ $\forall r \epsilon REG$
(F3) $APE(i,i,r) = 2.0 * \alpha(i,r) - \sum_{m \epsilon TRAD} [CONSHR(m,r) * \alpha(m,r)] - \alpha(i,r)/CONSHR(i,r)$	$\forall i \epsilon TRAD$ $\forall r \epsilon REG$
(F4) $EY(i,r) = [\sum_{m \epsilon TRAD} CONSHR(m,r) * \gamma(m,r)]^{-1} * \gamma(m,r) * [1.0 - \alpha(i,r)] + \sum_{m \epsilon TRAD} CONSHR(m,r) * \gamma(m,r) * \alpha(m,r) + \{\alpha(i,r) - \sum_{m \epsilon TRAD} [CONSHR(m,r) * \alpha(m,r)]\}$	$\forall i \epsilon TRAD$ $\forall r \epsilon REG$
(F5) $EP(i,k,r) = [APE(i,k,r) - EY(i,r)] * CONSHR(k,r)$	$\forall i \epsilon TRAD$ $\forall k \epsilon TRAD$ $\forall r \epsilon REG$

Table 2.14. *Supply of Sluggish Endowments*

(50) $pm(i,r) = \sum_{k \epsilon PROD\_COMM} REVSHR(i,k,r) * pmes(i,k,r)$	$\forall i \epsilon ENDWS$ $\forall r \epsilon REG$
(51) $qoes(i,j,r) = qo(i,r) - endwslack(i,r) + \sigma_T(i) * [pm(i,r) - pmes(i,j,r)]$	$\forall i \epsilon ENDWS$ $\forall j \epsilon PROD$ $\forall r \epsilon REG$

must precede calibration of the income elasticities. Finally, the two may be combined to yield the uncompensated, own-price elasticities of demand reported in (F5).

Imperfect factor mobility

The two equations in Table 2.14 describe the responsiveness of imperfectly mobile factors of production to changes in the rental rates associated with those sectors in which these sluggish factors are employed. The mobility of these endowments is described with a CET revenue function (Powell and Gruen 1968), which is completely analogous to the CES cost functions used above, except the revenue function is *convex in prices*. Thus the elasticity of transformation is nonpositive, $\sigma_T < 0$. As σ_T becomes larger in absolute value, the degree of sluggishness diminishes and there is a tendency for rental rates across alternative uses to move together. As with the CES nests discussed above, the first equation (50) introduces a price index and the second equation (51) determines the transformation relationships. Note also that equation (51) is where we introduce the slack variable, to be used in those cases where the user wishes to fix the market price of a sluggish endowment commodity.

Macroeconomic closure

Having described the structure of final demand, as well as factor market closure in the GTAP model, it remains to discuss the determination of aggregate investment. Like most comparative static AGE models, GTAP does not account for macroeconomic policies and monetary phenomena, which are the usual factors explaining aggregate investment. Rather, we are concerned with simulating the effects of trade policy and resource-related shocks on the medium-term patterns of global production and trade. Because this model is neither an intertemporal model (e.g., McKibbin and Sachs 1991), nor sequenced through time to obtain a series of temporary equilibria (e.g., Burniaux and van der Mensbrugghe 1991), investment does not come "on-line" next period to affect the productive capacity of industries/regions in the model. However, a reallocation of investment across regions *will* affect production and trade through its effects on the profile of final demand. Therefore, it is important to give this some attention. Also, a proper treatment of the savings–investment link is necessary in order to complete the global economic system, thereby assuring consistency in our accounting.

Because there is no intertemporal mechanism for determination of investment, we face what Sen (1963) defined as a problem of *macroeconomic closure* [see also Taylor and Lysy (1979)]. Following Dewatripont and Michel (1987), we note that there are four popular solutions to the fundamental indeterminacy of investment in comparative static models. The first three are nonneoclassical closures in which investment is simply fixed and another source of adjustment is permitted. In the fourth closure investment is permitted to adjust; however, rather than including an independent investment relationship, it simply accommodates any change in savings.

In addition to adopting a closure rule with respect to investment, it is necessary to come to grips with potential changes in the current account. Many multiregion trade models have evolved as a set of single-region models that are linked via bilateral merchandise trade flows [e.g., early versions of the SALTER model, which evolved from the ORANI model of Australia; see also Lewis, Robinson, and Wang (1995)]. These models have no *global closure* with respect to savings and investment, but instead impose the macroeconomic closure at the regional level. Here it is common to force domestic savings and investment to move in tandem, by fixing the current account balance. To understand this, it is useful to recall the following accounting identity (e.g., Dornbusch 1980), which follows from equating national expenditure from the sources and uses sides:

$$S - I \equiv X + R - M, \tag{2.15}$$

which states that the national savings (S) minus investment (I) is identically equal to the current account surplus, where R is international transfer receipts. (In the GTAP data base we do not have observations on R, so it is set equal to zero and S is derived as a residual, which reflects national savings, net of the unobserved transfers.) By fixing the right-hand side of identity (2.15) one also fixes the difference between national savings (including government savings) and investment. This may be accomplished in the GTAP framework by fixing the trade balance [DTBAL(r) = 0, see equation (98) in Table 2.18] and freeing up either national savings [endogenize *saveslack*(r) in equation (38)] or investment [endogenize *cgdslack*(r) in equation (11′)].

If global savings equals global investment in the initial equilibrium, then the summation over the left-hand side of equation (2.15) equals zero and the sum of all current account balances must initially be zero (provided *cif/fob* margins are accounted for in national exports). Furthermore, by fixing the right-hand side of (2.15) on a regional basis, each region's share in the global pool of net savings is fixed. In this way, equality of global savings and investment in the new equilibrium is also assured, in spite of the fact that there is no "global bank" to intermediate formally between savings and investment on a global basis. Finally, since investment is forced to adjust in line with regional changes in savings, this approach clearly falls within the "neoclassical" closure, as identified by Dewatripont and Michel (1987).

The exogeneity of the current account balance embodies the notion that this balance is a macroeconomic, rather than microeconomic, phenomenon: to a great extent, the causality in identity (2.15) runs from the left side to the right side. It also facilitates analysis by forcing all adjustment to external imbalance onto the current account. If savings does not enter the regional utility function (as is the case in most multiregion AGE models outside of GTAP), this is also the right approach to welfare analysis because an arbitrary shift away from savings toward current consumption and increased imports would otherwise permit an increase in utility to be attained, even in the absence of improvements in efficiency or regional terms of trade.

For some types of experiments, however, modelers may wish to endogenize the balances on either side of identity (2.15). For example, some trade policy reforms raise returns to capital and/or lower the price of imported capital goods. In this case, we would expect the increased rate of return on new investment to result in an increase in regional investment and, *ceteris paribus*, a deterioration in the current account. In other cases one might wish to explore the implications of, for example, an *exogenous* increase in foreign direct investment, which would also dictate a deterioration in the current account. Once the left-hand side of (2.15) is permitted to adjust, a mechanism is needed to ensure that the global demand for savings equals the global demand for investment in the postsolution equilibrium. The easiest way to do so is through the use of a "global bank" to assemble savings and disburse investment. This is the approach that we adopt here.

The global bank in the GTAP model uses receipts from the sale of a homogeneous savings commodity to the individual regional households in order to purchase (at price *PSAVE*) shares in a portfolio of regional investment goods. The size of this portfolio adjusts to accommodate changes in global savings. Therefore, the *global closure* in this model is neoclassical. However, on a regional basis, some adjustment in the mix of investment is permitted, thereby adding another dimension to the determination of investment in the model.

Fixed capital formation and allocation of investment across regions

We have incorporated two alternative investment components into the model. The user may choose which "theory" to employ, depending on her or his individual needs and the simulation being conducted. The first investment component enforces a close link between regional rates of return on capital. This component is described in equations (2.16)–(2.26) below. It draws on the formulation used to allocate investment across *sectors* in the ORANI model (Dixon et al. 1982). The second investment component is based on the assumption that the regional composition of global capital stock will be left unaltered in the simulation, and it is described in equations (2.26) and (2.27) below. At the end of this section we incorporate these two alternative investment components into a single set of composite equations, and explain how the user may specify which is to be used.

We begin by assuming that the productive capacity of capital declines geometrically over time, with depreciation rate $DEPR(r)$. As a result the end-of-period capital stock, $KE(r)$, is equal to the beginning-of-period capital stock, $KB(r)$, multiplied by $[1 - DEPR(r)]$ and augmented by gross investment, *REGINV(r)*. This accounting relationship is shown in the lower part of Table 2.7 and it is reproduced below:

$$KE(r) = KB(r) * [1 - DEPR(r)] + QCGDS(r). \tag{2.16}$$

We differentiate both sides of accounting relationship (2.16) to obtain:

$$dKE(r) = [1 - DEPR(r)]\ dKB(r) + dQCGDS(r), \tag{2.17}$$

which may be rewritten in terms of percentage changes as:

$$\begin{aligned} ke(r) = {} & [1 - DEPR(r)] * [KB(r)/KE(r)] * kb(r) \\ & + [QCGDS(r)/KE(r)] * qcgds(r), \end{aligned} \tag{2.18}$$

where variables in lowercase represent the percentage change of the corresponding level variables in uppercase.

Let us now define the ratio of investment to end-of-period capital stock, *INVKERATIO(r), as:*

$$\begin{aligned} INVKERATIO(r) &= PCGDS(r) * [QCGDS(r)/KE(r)] \\ &= REGINV(r)/VKE(r) \end{aligned}$$

and note that

$$\begin{aligned} [1 - DEPR(r)] * [KB(r)/KE(r)] &= \{VKB(r)[1 - DEPR(r)] \\ &\quad + REGINV(r) - REGINV(r)\}/VKE(r) \\ &= \{VKE(r) - REGINV(r)\}/VKE(r) \\ &= 1 - INVKERATIO(r). \end{aligned}$$

We substitute this into (2.18) to obtain the following relation:

$$ke(r) = [1 - INVKERATIO(r)] * kb(r) + INVKERATIO(r) * qcgds(r). \tag{2.19}$$

This is equation (10) in Table 2.8.

We then define the current net rate of return on fixed capital in region *r*, *RORC(r)*, as the ratio of the rental for capital services, *RENTAL(r)*, to the purchase price of capital goods, *PCGDS(r)*, less the rate of depreciation, *DEPR(r)*:

$$RORC(r) = RENTAL(r)/PCGDS(r) - DEPR(r). \tag{2.20}$$

Expressing equation (2.20) in percentage change terms, we obtain:

$$rorc(r) = [RENTAL(r)/(RORC(r) * PCGDS(r))] * [rental(r) - pcgds(r)]. \tag{2.21}$$

Table 2.15. *Investment Equations*

Equations of notational convenience

(52) $$ksvces(r) = \sum_{h \in ENDWC} [VOA(h,r) / \sum_{k \in ENDWC} VOA(k,r)] * qo(h,r) \qquad \forall r \in REG$$

(53) $$rental(r) = \sum_{h \in ENDWC} [VOA(h,r) / \sum_{k \in ENDWC} VOA(k,r)] * ps(h,r) \qquad \forall r \in REG$$

(54) $$qcgds(r) = \sum_{h \in CGDS} [VOA(h,r) / REGINV(r)] * qo(h,r) \qquad \forall r \in REG$$

(55) $$pcgds(r) = \sum_{h \in CGDS} [VOA(h,r) / REGINV(r)] * ps(h,r) \qquad \forall r \in REG$$

(56) $$kb(r) = ksvces(r) \qquad \forall r \in REG$$

Rate of return equations

(57) $$rorc(r) = GRNETRATIO(r) * [rental(r) - pcgds(r)] \qquad \forall r \in REG$$

(58) $$rore(r) = rorc(r) - RORFLEX(r) * [ke(r) - kb(r)] \qquad \forall r \in REG$$

(11*) $$\begin{aligned} & RORDELTA * rore(r) + (1 - RORDELTA) \\ & * \{[REGINV(r)/NETINV(r)] * qcgds(r) - [VDEP(r)/NETINV(r)] * kb(r)\} \\ & = RORDELTA * rorg + (1 - RORDELTA) * globalcgds + cgdslack(r) \end{aligned} \qquad \forall r \in REG$$

(59) $$\begin{aligned} & RORDELTA * globalcgds + (1 - RORDELTA) * rorg = \\ & RORDELTA * \sum_{r \in REG} \{[REGINV(r)/GLOBINV] * qcgds(r) - [VDEP(r)/GLOBINV] * kb(r)\} \\ & + (1 - RORDELTA) * \sum_{r \in REG} [NETINV(r)/GLOBINV] * rore(r) \end{aligned}$$

Price of Savings

(60) $$psave = \sum_{r \in REG} NETINV(r)/GLOBINV * pcgds(r)$$

We note that

$$RENTAL(r)/[RORC(r) * PCGDS(r)] = [RORC(r) + DEPR(r)]/RORC(r), \tag{2.22}$$

and we define the ratio of gross returns [i.e., $RORC(r) + DEPR(r)$] to net returns as:

$$GRNETRATIO(r) = [RORC(r) + DEPR(r)]/RORC(r). \tag{2.23}$$

We substitute equations (2.22) and (2.23) into equation (2.21) to obtain equation (57) in Table 2.15.

For our rate-of-return investment component, we assume that investors are cautious in assessing the effects of net investment in a region. They behave as if they expect that region's rate of return in the next period, *RORE*(r), to decline with positive additions to the capital stock. The rate at which this decline is expected is a function of the flexibility parameter *RORFLEX*(r)>0:

$$RORE(r) = RORC(r)[KE(r)/KB(r)]^{-RORFLEX(r)}. \qquad (2.24)$$

Therefore, the elasticity of *RORE(r)* with respect to *KE(r)* is equal to minus *RORFLEX(r)*. Equation (2.24) in percentage change terms is given by equation (58) in Table 2.15. We then assume that investors behave in such a way that changes in regional rates of return are equalized across regions:

$$rore(r) = rorg, \qquad (2.25)$$

where *rorg* is the percentage change in a global rate of return. Thus, the model will distribute a change in global savings across regions in such a way that all *expected* regional rates of return change by the same percentage. A small value for *RORFLEX*(r), say, *RORFLEX*(r) = 0.5, implies that a 1% increase in *KE*(r) is expected to reduce the rate of return on capital by 0.5%. (For example, if the current rate of return were 10%, the expected rate of return on a net investment equal to 1% of *KE*(r) would be 9.995%, i.e., little change.) In this case the supply of new capital goods is *very* sensitive to the expected rate of return. In order to maintain equal changes in *RORE* across regions, the model will produce large changes in regional investment.

However, a large value for *RORFLEX*(r), say, *RORFLEX*(r) = 50, implies that a 1% increase in *KE*(r) is expected to cut the rate of return on capital in half. In this case the supply of new capital goods is not very sensitive to changes in the expected rate of return. Therefore, equal changes in *RORE* across regions can be accommodated with small changes in regional investment. In other words, if the user believes that the experiment under consideration will not have a great impact on regional investment (or wishes to abstract from such effects) large values of *RORFLEX*(r) should be chosen.

Relatively high values for the coefficient *RORFLEX*(r) are supported by the work of Feldstein and Horioka (1980). They correlated the share of gross domestic investment to gross domestic product with the share of gross domestic savings to gross domestic product (see Feldstein and Horioka 1980; Feldstein 1983). They found a close correlation between savings and investment, and they concluded that even between industrialized countries, international capital mobility may be limited.

The second investment component adopts an extreme position in which we assume that the regional composition of capital stocks will not change at all so that regional and global net investment move together:

$$globalcgds = [REGINV(r)/NETINV(r)] * qcgds(r) - [VDEP(r)/NETINV(r)] * kb(r), \qquad (2.26)$$

where *globalcgds* is the percentage change in global supply of new capital goods. In this case, the percentage change in the global rate of return on capital variable, *rorg*, is computed as a weighted average of regional variables (the latter being now wholly unrelated):

$$rorg = \sum_{r \in REG} [NETINV(r)/GLOBINV] * rore(r)$$

where

$$NETINV(r) = (REGINV(r) - VDEP(r)). \qquad (2.27)$$

To summarize, under the rate-of-return component, investment behavior is determined by equations (2.25) above and equation (11) in Table 2.8. Under the alternative component,investment behavior is determined by equations (2.26) and (2.27). Both systems are summarized in Table 2.16.

We have combined these two systems in equations (2.28) and (2.29), employing the parameter *RORDELTA*: this is a binary parameter that takes the values 0 and 1. For *RORDELTA*=1 we obtain the rate-of-return model, and for *RORDELTA*=0 we obtain the alternative model.

$$\begin{aligned} RORDELTA \quad & * rore(r) + (1 - RORDELTA) * \{[REGINV(r)/NETINV(r)] \\ & * qcgds(r) - [VDEP(r)/NETINV(r)] * kb(r)\} \\ = RORDELTA \ & * rorg + (1 - RORDELTA) * globalcgds \end{aligned} \qquad (2.28)$$

and

$$\begin{aligned} & RORDELTA * globalcgds + (1 - RORDELTA) * rorg \\ & = RORDELTA * \sum_{r \in REG} \{[REGINV(r)/GLOBINV] \\ & * qcgds(r) - [VDEP(r)/GLOBINV] * kb(r)\} \\ & + (1 - RORDELTA) * \sum_{r \in REG} [NETINV(r)/GLOBINV] * rore(r) \end{aligned} \qquad (2.29)$$

Equation (2.28) is shown in Table 2.15 as equation (59), and equation (2.29) is shown in Table 2.15 as equation (11′). It replaces equation (11) in Table 2.8.

Once the level of investment activity in each region has been determined, it remains only to generate the mix of expenditures for domestic and imported inputs used in the production of fixed capital in region *r*: *VDFA(i, "cgds",r)* and *VIFA(i, "cgds",r)*, respectively. This is completely analogous to the production of tradeable commodities. In fact, the same equations are used to generate these derived demands. We assume that a unit of capital for investment in region *r* is created by assembling composite intermediate inputs in fixed proportions [equation (36) in Table 2.11]. The composite intermediate input is, in turn, a CES combination of domestic and foreign imported inputs [equations (31) and (32) in Table 2.11 and equation (29) in Table 2.10]. However, in contrast to the

Table 2.16. ***Regional Allocation of Investment Under Alternative Closures***

Rate-of-return component:

$$rore(r) = rorg$$

$$globalcgds = \sum_{r \in REG} \{[REGINV(r) / GLOBINV] * qcgds(r) - [VDEP(r) / GLOBINV] * kb(r)\}$$

Alternative component:

$$globalcgds = [REGINV(r) / NETINV(r)] * qcgds(r) - [VDEP(r) / NETINV(r)] * kb(r)$$

$$rorg = \sum_{r \in REG} [NETINV(r) / GLOBINV] * rore(r)]$$

Table 2.17. *The Global Shipping Industry*

(7′) $VT * pt = \sum_{i \in TRAD} \sum_{r \in REG} VST(i,r) * pm(i,r)$	
(61) $qst(i,r) = qt + [pt - pm(i,r)]$	$\forall i \in TRAD$ $\forall r \in REG$
(62) $VT * qt = \sum_{i \in TRAD} \sum_{r \in REG} \sum_{s \in REG} VTWR(i,r,s) * [qxs(i,r,s) - atr(i,r,s)]$	
(26′) $pcif(i,r,s) = FOBSHR(i,r,s) * pfob(i,r,s) + TRNSHR(i,r,s) * [pt - atr(i,r,s)]$	$\forall i \in TRAD$ $\forall r \in REG$ $\forall s \in REG$

production of tradeable commodities, capital creation requires no services of primary factors. This is because it is a fictitious activity that merely assembles goods destined for fixed investment in region r. In other words, the use of land, labor, and capital associated with capital formation is already embodied in the intermediate inputs assembled by this investment sector.

Global transportation

In addition to the global bank, another global activity is required in this model in order to intermediate between the supply of, and demand for, international transport services. These services are provided via a Cobb–Douglas production function that demands, as inputs, services exports from each region. Lacking the data to link exports of transport services with specific routes, we simply combine these services into a single composite international transport good, the value of which is $VT = QT * PT$. The percentage change equation for the composite price index was given in equation (7) of Table 2.8. For convenience, it is repeated as equation (7′) in Table 2.17. Recall that this is akin to a zero profit condition for the aggregate transport sector. The next equation (61) in Table 2.17 derives the conditional demands for the inputs to the shipping services sector, assuming that the share of each region in the global industry is constant, that is, Cobb–Douglas technology. Therefore, this equation includes an expansion effect (qt) and a substitution effect, whereby the elasticity of substitution is assumed to be unitary.

The next two equations in Table 2.17 refer to the uses of the composite international shipping service. We assume that this composite is employed in fixed proportions with the volume of a particular good shipped along a particular route, $QXS(i,r,s)$. In other words: $ATR(i,r,s) * QTS(i,r,s) = QXS(i,r,s)$, where $QTS(i,r,s)$ is the amount of the homogeneous product QT used in shipping of commodity *i* from *r* to *s*, and *ATR(i,r,s)* is a technical coefficient. Equilibrium in the global transport services market therefore requires that:

$$\sum_{i \in TRAD} \sum_{r \in REG} \sum_{s \in REG} QTS(i,r,s) = QT. \tag{2.30}$$

Proportionately differentiating this equation gives:

$$\sum_{i \in TRAD} \sum_{r \in REG} \sum_{s \in REG} QTS(i,r,s) * qts(i,r,s) = QT * qt. \tag{2.31}$$

Multiplying both sides by the common price of the composite transport service, and substituting [*qxs(i,r,s)* − *atr(i,r,s)*] for *qts(i,r,s)* gives equation (62) in Table 2.17. The presence of *atr(i,r,s)* in this formulation permits the user to introduce commodity / route-specific technical change in international transport services. This also requires us to modify the *fob/cif* price linkage equation (26) in Table 2.9 to reflect the fact that an increase in efficiency along a particular route will lower *cif* values, for a given *fob* price. This revision is reported in (26′) of Table 2.17.

Summary indices

This section discusses the summary indices computed in the GTAP model. These equations do not play a role in determining the equilibrium solution. Indeed, all these indices *could* be computed after the fact. However, it is convenient to include them in the model so that their rates of change are reported along with the other results. Table 2.18 shows aggregate indices of prices received [*psw(r)*, equation (64)] and prices paid [*pdw(r)*, equation (65)] for products sold and purchased by each region (inclusive of savings and investment, which represent transactions with the global bank). The difference between *psw(r)* and *pdw(r)* measures the percentage change in each region's terms of trade, *tot(r)*.

GTAP also computes regional equivalent variation measures, *EV(r)*, which arise due to the simulation under consideration. The values for *EV(r)* are in 1992 $US million, and they are computed as:[8]

$$EV(r) = u(r) * INC(r) / 100.$$

Since *u(r)* reports the percent change in per capita welfare, equation (67) in Table 2.18 also includes the rate of change in population on the right-hand side so that the *EV* reported by the model represents total regional welfare. The worldwide equivalent variation (WEV) is then computed as the simple summation of the regional *EV*s, equation (68). This is followed by an equation generating the percentage in the region-specific consumer price index, *ppriv(r)*.

Other useful price and quantity indices included in GTAP refer to trade, regional gross domestic product (GDP), and income magnitudes. To obtain

Table 2.18. *Summary Indices*

$$(64)\quad VWLDSALES(r) * psw(r) = \sum_{i\in TRAD}\sum_{s\in REG} VXWD(i,r,s) * pfob(i,r,s) + VST(i,r) * pm(i,r) + [REGINV(r) - VDEP(r)] * pcgds(r) \qquad \forall r\in REG$$

$$(65)\quad VWLDSALES(r) * pdw(r) = \sum_{i\in TRAD}\sum_{k\in REG} VIWS(i,k,r) * pcif(i,k,r) + SAVE(r) * psave \qquad \forall r\in REG$$

$$(66)\quad tot(r) = psw(r) - pdw(r) \qquad \forall r\in REG$$

$$(67)\quad EV(r) - [INC(r)/100] * [URATIO(r) * POPRATIO(r)] * [u(r) + pop(r)] = 0 \qquad \forall r\in REG$$

$$(68)\quad WEV - \sum_{r\in REG} EV(r) = 0 \qquad \forall r\in REG$$

$$(69)\quad PRIVEXP(r) * ppriv(r) = \sum_{i\in TRAD} VDA(i,r) * pp(i,r) \qquad \forall r\in REG$$

$$(70)\quad GDP(r) * vgdp(r) = \sum_{i\in TRAD} VGA(i,r) * [pg(i,r) + qg(i,r)] + \sum_{i\in TRAD} VPA(i,r) * [pp(i,r) + qp(i,r)] + REGINV(r) * [pcgds(r) + qcgds(r)] + \sum_{i\in TRAD}\sum_{s\in REG} VXWD(i,r,s) * [pfob(i,r,s) + qxs(i,r,s)] + \sum_{i\in TRAD} VST(i,r) * [pm(i,r) + qst(i,r)] - \sum_{i\in TRAD}\sum_{r\in REG} VIWS(i,r,s) * [pcif(i,r,s) + qxs(i,r,s)] \qquad \forall r\in REG$$

$$(71)\quad GDP(r) * pgdp(r) = \sum_{i\in TRAD} VGA(i,r) * pg(i,r) + \sum_{i\in TRAD} VPA(i,r) * pp(i,r) + REGINV(r) * pcgds(r) + \sum_{i\in TRAD}\sum_{s\in REG} VXWD(i,r,s) * pfob(i,r,s) + \sum_{i\in TRAD} VST(i,r) * pm(i,r) - \sum_{i\in TRAD}\sum_{r\in REG} VIWS(i,r,s) * pcif(i,r,s) \qquad \forall r\in REG$$

$$(72)\quad qgdp(r) = vgdp(r) - pgdp(r) \qquad \forall r\in REG$$

$$(73)\quad VXW(i,r) * vxwfob(i,r) = \sum_{s\in REG} VXWD(i,r,s) * [qxs(i,r,s) + pfob(i,r,s)] + VST(i,r) * [qst(i,r) + pm(i,r)] \qquad \forall i\in TRAD,\ \forall r\in REG$$

quantity indices, it is necessary to compute the corresponding value and price indices first, because we are aggregating over different commodities. For example, variable *qgdp(r)*, equation (72) of Table 2.18, is a quantity index for domestic product.[9] Table 2.18 shows that we first compute a value index, *vgdp(r)*, in equation (70), which accounts for changes in prices and quantities, and a price index, *pgdp(r)*, in equation (71), which accounts for changes in prices only. The quantity index, *qgdp(r)*, is then computed as the difference between *vgdp(r)* and *pgdpr(r)*. For simulations of trade and domestic policy

Table 2.18. *(cont.) Summary Indices*

(74) $VIW(i,s) * viwcif(i,s) = \sum_{r\in REG} VIWS(i,r,s) * [pcif(i,r,s) + qxs(i,r,s)]$	$\forall i\in TRAD$ $\forall s\in REG$
(75) $VXWREGION(r) * vxwreg(r) = \sum_{i\in TRAD} VXW(i,r) * vxwfob(i,r)$	$\forall r\in REG$
(76) $VIWREGION(s) * viwreg(s) = \sum_{i\in TRAD} VIW(i,s) * viwcif(i,s)$	$\forall s\in REG$
(77) $VXWCOMMOD(i) * vxwcom(i) = \sum_{r\in REG} VXW(i,r) * vxwfob(i,r)$	$\forall i\in TRAD$
(78) $VIWCOMMOD(i) * viwcom(i) = \sum_{s\in REG} viw(i,s) * viwcif(i,s)$	$\forall i\in TRAD$
(79) $VXWLD * vxwwld = \sum_{r\in REG} VXWREGION(r) * vxwreg(r)$	
(80) $VWOW(i) * valuew(i) = \sum_{r\in REG} VOW(i,r) * [pxw(i,r) + qo(i,r)]$	$\forall i\in TRAD$
(81) $VXW(i,r) * pxw(i,r) = \sum_{s\in REG} VXWD(i,r,s) * pfob(i,r,s) + VST(i,r) * pm(i,r)$	$\forall i\in TRAD$ $\forall r\in REG$
(82) $VIW(i,s) * piw(i,s) = \sum_{r\in reg} VIWS(i,r,s) * pcif(i,r,s)$	$\forall i\in TRAD$ $\forall r\in REG$
(83) $VXWREGION(r) * pxwreg(r) = \sum_{i\in TRAD} VXW(i,r) * pxw(i,r)$	$\forall r\in REG$
(84) $VIWREGION(s) * piwreg(s) = \sum_{i\in TRAD} VIW(i,s) * piw(i,s)$	$\forall s\in REG$
(85) $VXWCOMMOD(i) * pxwcom(i) = \sum_{r\in REG} VXW(i,r) * pxw(i,r)$	$\forall i\in TRAD$
(86) $VIWCOMMOD(i) * piwcom(i) = \sum_{s\in REG} VIW(i,s) * piw(i,s)$	$\forall i\in TRAD$
(87) $VXWLD * pxwwld = \sum_{r\in REG} VXWREGION(r) * pxwreg(r)$	
(88) $VWOW(i) * pw(i) = \sum_{r\in REG} VOW(i,r) * pxw(i,r)$	$\forall i\in TRAD$

changes, the solution value for $qgdp(r)$ will typically be small, reflecting only shifts in the economy's production possibilities frontier owing to the improved allocation of a fixed resourcebase. But for simulations of endowment growth, the solution value for $qgdp(r)$ will provide a summary measure of growth for the region.

We next turn to a set of equations defining changes in aggregate trade values, prices, and quantity indices. Equations (73)–(78) compute the percentage change in export and import values: (1) by commodity *and* region, (2) by

Table 2.18. *(cont.) Summary Indices*

(89) $qxw(i,r) = vxwfob(i,r) - pxw(i,r)$	$\forall i \in TRAD$ $\forall r \in REG$
(90) $qiw(i,s) = viwcif(i,s) - piw(i,s)$	$\forall i \in TRAD$ $\forall s \in REG$
(91) $qxwreg(r) = vxwreg(r) - pxwreg(r)$	$\forall r \in REG$
(92) $qiwreg(s) = viwreg(s) - piwreg(s)$	$\forall s \in REG$
(93) $qxwcom(i) = vxwcom(i) - pxwcom(i)$	$\forall i \in TRAD$
(94) $qiwcom(i) = viwcom(i) - piwcom(i)$	$\forall i \in TRAD$
(95) $qxwwld = vxwwld - pxwwld$	
(96) $qow(i) = valuew(i) - pw(i)$	$\forall i \in TRAD$
(97) $DTBALi(i,r) = [VXW(i,r)/100] * vxwfob(i,r) - [VIW(i,r)/100] * viwcif(i,r)$	$\forall i \in TRAD$ $\forall r \in REG$
(98) $DTBAL(r) = [VXWREGION(r)/100] * vxwreg(r) - [VIWREGION(r)/100] * viwreg(r)$	$\forall r \in REG$

region for all traded commodities, and (3) by commodity for all regions in the world. Equation (79) computes the percentage change in the value of total world trade, and equation (80) computes the percentage in value of world output, by commodity.[10] These are followed by eight analogous equations, (81)–(88), which compute the associated price indices, after which we are able to extract pure volume changes for aggregate trade and output [equations (89)–(96)].

The last two equations in the model are given at the bottom of Table 2.18. They are used to compute the change in trade balance, by commodity and by region. This is a value-based concept, and *DTBAL*(*r*), equation (98), refers to the changes in the current account for each region.

VII A simple numerical example

Perhaps the best way to understand how this model works is to perform a simple experiment and examine the resulting changes in endogenous variables of interest. (This is example 21 in the Hands-On document, referred to in Chapter 6, and available through the Web site.) In order to keep things simple, we will work with a three-commodity/three-region aggregation of the data base. The three commodities are: food, manufactures, and services. The three regions are: the United States (US), the European Union (EU), and the rest

Table 2.19. *Impact of a 10% Cut in the Power of the Ad Valorem Tariff on EU Imports of US Foods on EU Food Sector in a Standard GE Closure using Johansen Solution Method and Fixed Investment Portfolio (RORDELTA = 0)*

VARIABLE	*PERCENTAGE CHANGE*	*EQUATION #*
pm(food, usa) = .140		
pfob(food, usa, eu) = .140	(*tx*, *txs* exogenous)	(27)
pcif(food, usa, eu) = .124	= (.893) * (.140) + (.107) * (-.008)	(26)
pms(food, usa, eu) = -9.876	= .124 - 10.0	(24)
pim(food, eu) = -1.631	= (.164) * (-9.876) + (.000) * (-.121) + (.836) * (-.016)	(28)
qxs(food, usa, eu) = 41.433	= 3.18 - (4.64) * [-9.876 - (-1.631)]	(29)
pf(food, food, eu) = -.259	= .092 * (-1.631) + .908 * (-.121)	(30)
qfm(food, food, eu) = 3.002	= -.288 - (2.40) * [-1.631 - (-.259)]	(31)
qfd(food, food, eu) = -0.621	= -.288 - (2.40) * [-.121 - (-.259)]	(32)
ps(food, eu) = -0.121		(1)

* Equation numbers refer to GTAP model equations presented in earlier tables.

of the world (ROW). The experiment involves a bilateral reduction in the level of the EU's import tariff onUS food products. In particular, *tms(food,usa,eu)* = −10%. This implies a cut of 10% in the *power of the ad valorem tariff*, which amounts to a 10% cut in the domestic price of US food exports to the EU, *ceteris paribus*. Furthermore, we begin by performing only the *first step* in a multistep solution of the model developed above. In terms of Figure 2.5, this means we are moving from (X_0, Y_0) to (X_1, Y_J), where Y_J is a Johansen approximation to Y_1 (the true solution). This is merely a pedagogical device to facilitate discussion of our example, since in the Johansen solution, the linearized form of the model in Tables 2.8–2.18 will *hold exactly*. For small shocks this may provide a reasonable approximation to the true, nonlinear price and quantity changes. However, *it is a very poor method for assessing welfare changes* [see Hertel, Horridge, and Pearson (1992) for an extensive discussion of these issues]. The reader can observe this approximation error by comparing the Johansen solution with the Gragg outcomes (given in brackets) in Tables 2.20, 2.22, and 2.23.

Tables 2.19 and 2.20 report selected changes in the EU, resulting from the bilateral tariff cut. We begin at the top of the table, with the market price of US food in the US. This market price rises by 0.140% due to increased demand. Since there is no change in the border tax, *pfob* rises by the same amount, via equation (27) in Table 2.9. The *cif* price of US food exports to the EU depends also on changes in the price index of international transport

Table 2.20. ***Economywide Effects in EU of a 10% Cut in the Power of the Ad Valorem Tariff on EU Imports of US Food in a Standard GE Closure Using Johansen Solution Method and RORDELTA = 0 (Nonlinear solution in brackets)***

COMMODITY	VARIABLE (PERCENTAGE CHANGE)					
	pm(i, eu)[a]		qo(i, eu)		qp(i, eu)	
Land	-.414	[-.515][b]	0.0	[0]	na	[na]
Labor	-.029	[-.041]	0.0	[0]	na	[na]
Capital	-.028	[-.041]	0.0	[0]	na	[na]
Food	-.121	[-.154]	-.288	[-.355]	.036	[.042]
mnfrs	-.030	[-.041]	.064	[.086]	.012	[.007]
Services	-.030	[-.042]	.012	[.012]	.011	[.007]
cgds	-.026	[-.037]	-.003	[-.004]	na	[na]

[a] All price changes are relative to the price of the numeraire, which is savings.
[b] Nonlinear solution obtained by applying the Gragg, 2-4-6, method.

services, *pt*. This drops slightly due to the decline in the price of EU transport services [Table 2.19 and equation (7)]. Therefore, *pcif* increases by a slightly smaller amount.

The bilateral tariff instrument, which is the subject of this experimental shock, enters via equation (24) in Table 2.9. Its reduction serves to lower the domestic market price of EU food imports from the US, *pms* (*food,usa,eu*), by 9.876%. This price cut has two immediate effects. First, it lowers the price of composite imports by 1.631% [equation (28) in Table 2.10], a value that is roughly equal to the share of US imports in total expenditures on imported food multiplied by –9.876%. The second immediate effect of this price cut is that it encourages agents in the EU to alter their sourcing of food imports in favor of US products [equation (29) in Table 2.10]. The responsiveness of this shift in the model is dictated by the elasticity of substitution among food imports (σ_M). Its value in the aggregated data base is 4.64. This figure is multiplied by the percentage change in the cost of food imports from the US, relative to composite import costs, or the difference in these two individual percentage changes. This equals 38.26%. If the level of imports *qim* were unchanged, this would be the end of the story. However, the impact of the bilateral cut in protection continues, since the cheaper imports result in a substitution of composite imports for domestic food. This effect varies by sector in this model, due to the differing importance of imports in the composite intermediate good. Since the substitution structure in each of these is very similar, we choose to focus on the EU food industry, which is the largest user, accounting for 52.7% of total food imports in that market. In this industry, aggregate imports increase by 3.18%. Thus the total increase in US food imports by the EU food industry is equal to 41.4%.

The numerical implementations of equations (30) and (31) in Table 2.11 describe the changes at the next level of the production tree (recall Figure

2.3). They account for the 3.0% increase in composite food imports by this sector. However, note from equation (31) that in this case the expansion and substitution effects work in opposite directions, since *qf(food,eu)* = *qo(food,eu)* < 0. That is, the food sector as a whole contracts, and with it, there is a decline in the demand for intermediate products, in this case food. Equation (32) shows that the demand for domestically produced intermediates actually falls. Finally, owing to a decline in the total demand for domestically produced food, the price of EU-produced food falls.

Table 2.20 reports selected price and quantity changes for the EU as a whole, owing to this bilateral tariff cut. The price of farmland falls, since this factor has no alternative uses outside of the food sector in our model, and output in that sector has declined. With labor and capital being released from the food sector, the nonfood sectors are able to expand. In general equilibrium, households increase their consumption of all nonsavings commodities due to the lower prices. The demand for savings falls, since its price is determined by a weighted combination of the capital goods prices from all regions, which tend to rise relatively more than other goods prices.

Now turn to the effects of the tariff cut on the US economy, which are reported in Tables 2.21 and 2.22. Equation (1) in Table 2.21 combines the increase in US–EU exports, together with changes in sales to other destinations/uses in order to estimate the change in food sector output in the US. The first figures in parentheses are the shares of sales to various uses. From this, it can be seen that exports to the EU account for only 1.3% of the value of total US food sector output (at domestic market prices). This considerably tempers the impact of the 41.4% increase in sales. Of course the importance of this market for selected, *disaggregated* producer groups can be much larger, and might warrant strategic disaggregation of the data base to capture such effects.

It is not surprising that the bulk of US food sales goes to the domestic market (92.6%). However, it is somewhat surprising that the tariff cut in the EU causes domestic sales of US food to *increase*. More insight into this result may be obtained by considering the numerical implementation of equation (3) in Table 2.21. This shows the changes in composition of domestic sales. As expected, sales to other industries and final demand fall, as US supply prices for food are bid up by the EU users. However, these declines are more than offset by an increase in *intermediate* demands for food in the US food sector. In other words, to meet the increased demand for food in the EU, domestic sales of intermediate goods must also increase.

Table 2.22 describes the economywide effects of the bilateral tariff cut on the US. Here, the land rental rate rises by more than the food price, and labor and capital wages rise by somewhat less, with the relative capital intensity of the food sector favoring capital over labor. Continuing the analogy, we see

Table 2.21. *Impact of a 10% Cut in the Power of the Ad Valorem Tariff on EU Imports of US Food on Total Food Sales in the US in a Standard GE Closure Using Johansen Solution Method and RORDELTA = 0*

VARIABLE	*PERCENTAGE CHANGE*	*EQUATION #*
$qo(food, usa)$ = 0.688		(1)[a]
= $SHRODM(food, usa) * qds(food, usa)$ → (.926) * (.207)		
$SHROTM(food, usa) * qst(food, usa)$ → (.000) * (.000)		
$\sum_j SHROXMD(food, usa, s) * qxs(food, usa, s)$		
	$s = usa$ → (.000) * (.-.133)	
	$s = eu$ → (.013) * (41.433)	
	$s = row$ → (.060) * (-.634)	
where:		
$qds(food, usa)$ = .207		(3)
= $\sum_j SHRDFM(food, j, usa) * qfd(food, j, usa)$		
	$j = food$ → (.334) * (.662)	
	$j = mnfcs$ → (.010) * (-.143)	
	$j = svcs$ → (.121) * (-.022)	
	$j = egds$ → (.000) * (-.042)	
+ $SHRDPM(food, usa) * qpd(food, usa)$ → (.517) * (-.019)		
+ $SHRDGM(food, usa) * qgd(food, usa)$ → (.018) * (-.031)		

[a] Equation numbers refer to GTAP model equations presented in earlier tables.

Table 2.22. *Economywide Effects in the US of a 10% Cut in the Power of the Ad Valorem Tariff on EU Imports of US Food in a Standard GE Closure Using Johansen Solution Method and RORDELTA = 0 (Nonlinear solution in brackets)*

COMMODITY	VARIABLE (Percentage Change)					
	pm(i, usa)[a]		*qo(i, usa)*		*qp(i, usa)*	
land	1.066	[1.378][b]	0	[0]	na	[na]
labor	.109	[.141]	0	[0]	na	[na]
capital	.125	[.162]	0	[0]	na	[na]
food	.140	[.181]	.688	[.886]	-.000	[-.000]
mnfrs	.100	[.129]	-.120	[-.155]	.037	[.048]
services	.111	[.144]	-.001	[-.001]	.009	[.011]
cgds	.095	[.123]	-.001	[-.002]	na	[na]

[a] All price changes are relative to the price of the numeraire, which is savings.
[b] Nonlinear solution obtained by applying the Gragg, 2-4-6, method.

Table 2.23. *Macroeconomic Effects of a 10% Cut in the Power of the Ad Valorem Tariff on EU Imports of US Food in a Standard GE Closure: Fixed (RORDELTA = 0) and Variable (RORDELTA = 1) Portfolios, and Johansen and Nonlinear Solution Methods Compared*

VARIABLE	US		EU		ROW	
	PERCENTAGE CHANGE					
qxwreg(r)	.138 (.057)[a]	[.178][b]	.233 (.263)	[.317]	-.007 (.007)	[-.006]
rorc(v)	.045 (.051)	[.059]	-.003 (-.005)	[-.006]	-.003 (-.004)	[-.003]
tot(v)	.110 (.128)	[.142]	-.043 (-.049)	[-.060]	-.007 (-.008)	[-.008]
up(r)	.013 (.016)	[.017]	.015 (.014)	[.013]	-.003 (-.004)	[-.004]
ug(r)	.013 (.015)	[.016]	-0.007 (-.008)	[-.014]	-.005 (-.006)	[-.006]
qsave(r)	.118 (.138)	[.153]	-.037 (-.042)	[-.056]	-.006 (-.007)	[-.006]
u(r)	.015 (.018)	[.019]	.006 (.004)	[.001]	-.004 (-.005)	[-.004]
	$US Million					
EV(r)[c]	778 (941)	[1004]	346 (251)	[62]	-347 (-410)	[-396]
DTBAL(r)	-8 (-663)	[-9]	0 (297)	[-22]	7 (366)	[31]

[a] Flexible investment portfolio, *RORDELTA* = 1, and Johansen solution method reported in parentheses.
[b] Fixed investment portfolio, *RORDELTA* = 0, and *nonlinear* solution obtained via Gragg, 2-4-6, method in brackets.
[c] Equivalent variation refers to the Cobb—Douglas, superutility function for region *r*. It is computed in equation (67) of Table 2.18.

that the manufacturing sector must contract in order to make way for expansion of the US food sector. Finally, note that composite consumption of nonfood manufactures and services increases, as households substitute imported for domestic goods.

The final table, Table 2.23, summarizes the macroeconomic effects of the EU's bilateral tariff cut. The increase in demand for US products bids up US prices, relative to the prices of products supplied from the EU and ROW. Since the EU must export more products to pay for the increase in food imports, their export volume increases by .233%, in the case where *RORDELTA* = 0 and a simple Johansen solution is used. (See the top entry in the second column of Table 2.23.) Therefore, the EU supply prices must fall relative to other regions. This results in a terms-of-trade deterioration for the EU, as seen in the third row of Table 2.23. The terms-of-trade for ROW are marginally worsened, due to displacement by US exporters. This translates into a welfare loss for ROW. In the EU, the terms-of-trade decline is more than offset by the improved allocation of domestic resources, and aggregate regional welfare rises by \$346 million. The US gains \$778 million due to its improved terms-of-trade, following the preferential cut in border taxes on US food exports to the EU.

It is interesting to note that the trade balance hardly changes, *DTBAL* (*r*) ≈ 0, in those simulations where *RORDELTA* = 0. This is a robust outcome that follows from equation (2.15) and the treatment of savings and investment in the model. The demand for savings is tied directly to income, which is little affected in this (and most other) policy reform experiments. Since regional savings doesn't change much, global savings, and hence global investment, are unaltered. Therefore, the only means of altering the left-hand side of (2.15), ($S - I$), and hence the trade balance, is to alter the regional allocation of investment. When *RORDELTA* = 0, this is not possible. Therefore, there can be little change in the right-hand side of (2.15), ($X - M$).

This is no longer true, however, when *RORDELTA* = 1, and the global bank's allocation of investment across regions is flexible. In the lower (parenthetical) entries of Table 2.23, we report results of the Johansen simulation with *RORFLEX* = 10 (the default setting for this parameter). Now changes in rate-of-return on investment come into play. From the second row of Table 2.23, we see that *rorc*(*eu*) < 0, since the rental rate on capital declines relative to the price of capital goods. Therefore, there is an incentive to divert some investment to other regions. Given S, the resulting decline in I requires an increase in ($X - M$) via identity (2.15). This is achieved by a slightly larger increase in export volume (.263% vs. .233%) from the EU, and a smaller increase in imports. Not surprisingly, this results in a stronger terms-of-trade deterioration and therefore a smaller gain in welfare, as opposed to the case where *RORDELTA* = 0.[11]

A comparison of the Johansen results with the nonlinear results (reported in brackets in Table 2.23) shows that the Johansen solution yields a poor approximation to the true welfare effects on the EU, even for this relatively small shock. This is because the change in EU utility reflects the difference between two larger changes, one of which is positive (efficiency gains) and one of which is negative (terms-of-trade effect). As can be seen from the third row of Table 2.23, the Johansen solution underestimates the true deterioration in the EU's terms of trade by a third. On the other hand, this solution procedure tends to *overstate* the gains from elimination of a distortion. Therefore, it is not surprising that the gain in EU welfare is *overstated* by more than five times (\$346 million vs. the true gain of \$62 million, reported in brackets). Indeed, it is not uncommon for such comparisons to yield sign reversals in some regions' welfare. In sum, use of the Johansen one-step solution procedure for purposes of decomposing small changes in prices and quantities (as in Tables 2.19 and 2.21) is very useful. However, *it is not an acceptable procedure for conducting welfare analysis of policy reforms*. For welfare analysis, the nonlinear solution procedures available in GEMPACK must be used.

VIII Summary

This completes our summary of the structure of the GTAP model. For your convenience, we have assembled a glossary of notation used in the model. This is provided at the back of this book. As noted, the electronic file, GTAP94.TAB, contains a complete listing of the model code. It is available on the Web site. Access to this site is discussed in Chapter 6. The best way to become familiar with the model is to apply it to a particular problem of interest. After covering the data base, the parameters, aggregation, and computing issues, we will turn to a set of seven diverse applications of this model.

NOTES

1. The authors would like to thank Martina Brockmeier for her development of much of this material. For a more extensive graphical exposition of the GTAP model, see Brockmeier (1996).
2. The motivation for including savings in this atemporal utility function derives from Howe (1975) and is discussed at greater length below.
3. In some cases the initial data base does not include taxation in these markets. However, the possibility of introducing such taxation is available in the model, and it must therefore be accounted for in the computation of regional income.
4. The most natural way to implement this model would be via a *mixed* levels and percentage change representation. Indeed, this is possible in GEMPACK (Harrison and Pearson 1994). However, it is computationally more burdensome. Also, by linearizing the accounting equations some additional insights may be obtained.
5. This type of nonlinear solution procedure is now the default option in GEMPACK. For an exhaustive comparison of the linearized and levels approaches to AGE modeling, the reader is referred to Hertel, Horridge, and Pearson (1992).
6. For the user with an interest in applications for which intermediate–intermediate and intermediate–primary factor substitution is important, it will be necessary to modify the basic model, tailoring it to the specific needs at hand. However, this is not particularly difficult, as will be seen below.
7. Howe (1975) also shows that the savings share parameter in the atemporal utility function can be related to 1 minus the ratio of consumer's rate of time preference to the rate of reproduction of capital.
8. The coefficient $INC(r)$ reports *initial* equilibrium values for regional expenditure (which must equal income).
9. Values for the coefficient gross domestic product, $GDP(r)$, are computed as follows:

$$GDP(r) = \sum_{i \in TRAD}[VGA(i,r) + VPA(i,r)] + VOA(\text{“}CGDS\text{”},r)$$
$$+ \sum_{i \in TRAD}\sum_{s \in REG}\mathrm{VXWD}(i,r,s) + \sum_{i \in TRAD}\mathrm{VST}(i,r) - \sum_{i \in TRAD}\sum_{r \in REG}\mathrm{VIWS}(i,r,s).$$

10. The coefficient $VOW(i,r)$ measures the value of regional production at world prices, and its values are computed as follows: $VOW(i,r) = VDM(i,r) * PW\_PM(i,r) + \sum_{s \in REG} VXWD(i,r,s)$. The coefficient $PW\_PM(i,r)$ converts domestic use valued at market prices, $VDM(i,r)$, to world prices, and it is computed as follows: $PW\_PM(i,r) = \sum_{s \in REG} VXWD(i,r,s) / \sum_{s \in REG} VXMD(i,r,s)$.
11. The combination of $RORDELTA = 1$ and the Gragg nonlinear solution procedure actually gives a slight *decline* in EU welfare.

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CHAPTER 3

Overview of the GTAP data base

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I Introduction and overview

The centerpiece of the Global Trade Analysis Project (GTAP) data base consists of bilateral trade, transport, and protection matrices that link 24 country/regional economic data bases. (See Table 3.1 for a complete list of regions and sectors in version 2 of the GTAP data base.[1]) The regional data bases are derived from individual country input–output tables.[2] The purpose of this chapter is to document the sources and procedures used in constructing the disaggregated 37-sector, 24-region data base that forms the basis for subsequent applications.

The next section discusses processing of the international bilateral merchandise trade data, which are published by the Statistical Office of the United Nations. These data are ideal for our purposes, but their reliability is questionable [see, for example, DeWulf (1981); Hiemstra and Mackie (1986); and Tsigas, Hertel, and Binkley (1992)]. Therefore, we discuss a statistical procedure for reconciling discrepant trade statistics and producing balanced bilateral trade and transport matrices for 1992. These bilateralized flows are also used to determine the pattern of trade in nonfactor services.

The third section discusses the support and protection data developed for GTAP. These are expressed in the form of *ad valorem* equivalent, tariff, and nontariff barriers, and they draw heavily on information submitted to the General Agreement on Tariffs and Trade (GATT) in connection with the Uruguay Round negotiations. For this reason, there is not a unique base year. However, these protection data are broadly indicative of the level of support prevailing prior to the Uruguay Round.

We then turn to the basic input–output (IO) data that provide information about the individual regional economies in GTAP. Some of these were obtained from the Australian Industry Commission (IC), while others were contributed

Table 3.1. *Regions and Commodities in Version 2 of the GTAP Data Base*[a]

Listing of regions in the data base
1. Australia (AUS)
2. New Zealand (NZL)
3. Canada (CAN)
4. United States of America (US)
5. Japan (JPN)
6. Republic of Korea (KOR)
7. EU-12 (EU)
8. Indonesia (IND)
9. Malaysia (MYS)
10. Philippines (PHL)
11. Singapore (SGP)
12. Thailand (THA)
13. People's Republic of China (CHN)
14. Hong Kong (HKG)
15. Taiwan (TWN)
16. Argentina (ARG)
17. Brazil (BRA)
18. Mexico (MEX)
19. Rest of Latin America (LAM)
20. Sub-Saharan Africa (SSA)
21. Middle East and North Africa (MNA)
22. Eastern Europe and Former Soviet Union (EIT)
23. South Asia (SAS)
24. Regions not elsewhere classified (ROW)

Listing of industries/commodities
1. Paddy rice (PDR)
2. Wheat (WHT)
3. Grains (other than rice and wheat: GRO)
4. Nongrain crops (NGC)
5. Wool (WOL)

Listing of industries (Cont'd)
6. Other livestock (OLP)
7. Forestry (FOR)
8. Fishing (FSH)
9. Coal (COL)
10. Oil (OIL)
11. Gas (GAS)
12. Other minerals (OMN)
13. Processed rice (PCR)
14. Meat product (MET)
15. Milk products (MIL)
16. Other food products (OFP)
17. Beverages and tobacco (BT)
18. Textiles (TEX)
19. Wearing apparel (WAP)
20. Leather, etc. (LEA)
21. Lumber and wood (LUM)
22. Pulp, paper, etc. (PPP)
23. Petroleum and coal products (PC)
24. Chemicals, rubber and plastics (CRP)
25. Nonmetallic mineral products (NMM)
26. Primary ferrous metals (IS)
27. Nonferrous metals (NFM)
28. Fabricated metal products nec. (FMP)
29. Transport equipment (TRN)
30. Machinery and equipment (OME)
31. Other manufacturing (OMF)
32. Electricity, water, and gas (EGW)
33. Construction (CNS)
34. Trade and transport (TT)
35. Other services (private) (OSP)
36. Other services (government)(OSG)
37. Ownership of dwellings (DWE)

[a] See also GTAP mapping file, available on the FTP site.

by members of the GTAP network. In the case of the six composite regions in the data base, no IO information is available, so we use representative combinations of the known tables to obtain estimated IO tables. The procedures for doing so are described in some detail in this section.

Because the IO tables making up the regional data bases refer not to 1992, but rather to the latest available year, they must be updated to conform to the 1992 trade and macroeconomic data. We accomplish this complicated task using the FIT software package (James and McDougall 1993). Once this is done, the trade and regional data bases may be merged. If everything has been done correctly, the data base balances and the sum of all region' savings (income private and public consumption) must, by virtue of Walras' Law, equal global investment. This offers a final consistency check on the GTAP data base.

II International trade data

This section covers development of the GTAP bilateral trade data base.[3] We begin with a discussion of the basic source of global bilateral trade data and the problems encountered in using it for analytical purposes. We then turn to some issues of data consistency, followed by a discussion of reconciliation procedures.

Institutional background

The trade data upon which the GTAP data base is built originate from United Nations D-series trade statistics. COMTRADE (COMmodity TRADE) is the registered name of the data base maintained by the United Nations (UN) Statistical Office. This data base is one of the most complete and exhaustive data bases in terms of commodity and country coverage. It is a daunting task to maintain a data base of this size, with contributions from all the countries of the world, so it is hardly surprising that there are problems of availability, quality, and consistency. In order to address these concerns, the UN established an interagency task force on international trade statistics. This task force has three main goals: (1) improving the flow of data from national authorities to the COMTRADE system, (2) adjusting reported data that do not comply with international guidelines to assure intercountry comparability, and (3) improving the estimation process used to create data files for those countries and periods for which no reported data are available. Thus far, most progress has been made in the area of the first goal.

The UN has made numerous attempts to estimate missing trade values. Traditionally, the UN Statistical Office has used a "gap filling" methodology called the Trade Estimation System (TESSY) to provide trade statistics for nonreported trade. This system employs a matrix balancing algorithm starting with known border sums. It fills in the unknown cells in the bilateral matrix. TESSY was started in 1979 in order to create estimates for all missing values in the UN trade data base and to provide a complete set of data with which to test the LINK project model. In fact, the UN maintains a data base of estimated data separate from the reported data contained in COMTRADE. However, this estimated data base is made available only to selected international agencies on a limited basis.

The disadvantage in using matrix balancing techniques such as TESSY is that there are an infinite number of solutions for a given problem. Therefore, it is difficult to place a particular degree of confidence in the balanced matrix. Responding to this dissatisfaction with existing methods, the Economic Research Service of the United States Department of Agriculture (USDA) has recently developed a new methodology to fill in missing gaps in the UN trade data. This methodology uses a statistical approach requiring time-series data. The statistical approach can yield more reliable estimates; however, it requires time-series data for each country. This limits country coverage to those that report on a reasonably regular basis. Estimates of missing data points with this approach were made at the 4-digit Standard International Trade Classification (SITC) level. The estimates provided by USDA/Economic Research Service (ERS) were merged with the UN COMTRADE data to create a starting point for the development of a GTAP trade data base. From there, the data are aggregated starting from the 4-digit SITC level to the 31 merchandise sectors in the GTAP data base. Once aggregated, specialized reconciliation procedures are employed. We next turn to a discussion of the issues and procedures of data reconciliation.

Concepts and definitions relevant to reconciliation

There are several perspectives on the meaning of consistency and reliability in trade data. For example, Rozanski and Yeats (1992) developed a method for evaluating UN trade statistics based on a set of consistency tests. These include checks on the consistency across SITC revisions; consistency checks within the SITC hierarchy levels, that is, 3-digit and 4-digit levels, and consistency across international agencies. It is beyond the scope of this project to test reliability or ensure the type of consistency proposed by Rozanski and Yeats. For the GTAP model to be operational there must ultimately be unification of reported export data with reported import data. This involves evaluating the consistency of trade data based on the partner country approach, that is, a country's reported exports (imports) are compared with a partner's reported imports (exports) with the objective of identifying major value differences (Morgenstern 1963; Yeats 1978). Counterpart trade statistics are consistent if: $X_{ij} = M_{ij}$, where X_{ij} is reported exports by the ith exporter to jth importer, and M_{ij} is reported imports by the jth importer from the ith exporter. In an overwhelming majority of cases, when two trading partners report the value of their trade to the UN, the export figures and the corresponding import figures disagree. This type of inconsistency is the focus of our reconciliation effort.

Reconciliation procedures

There is no common method for reconciling differences in counterpart trade statistics. Reconciliation methods vary according to the type of inconsistencies one perceives the need to resolve. Some argue that reported exports are more consistent than reported imports and that imports need to be adjusted in the reconciliation process. Arguments in favor of reported exports make the following points: (1) valuation conventions–export data are free of transportation and insurance charges, thus enhancing comparability across trade flows; and (2) ships do not appear in the import matrix.

Others contend that reported imports are more consistent than reported exports and the latter should be adjusted (Parniczky 1980). Arguments in favor of reported imports include: (1) underreporting of exports by customs authorities, (2) better commodity identification of imports due to closer inspection, and (3) uncertain destination of exports under the conditions created by entrepot trade.

We do not presume that reported exports are better or worse than reported imports. Rather, we examine this issue on a country-by-country, and commodity-by-commodity, basis. We regard countries that regularly under- or overreport trade figures as being "systematically biased." This is a statistical concept that may be formalized as follows. Let X_{ij} represent the observed export value (*fob*) reported by the *i*th country as exported to the *j*th country, and let X^*_{ij} represent the actual value (unobserved). The term β_i represents the "exporter bias" coefficient:

$$X_{ij} = \beta_i X^*_{ij}\ e_i. \tag{3.1}$$

The term β_i is a systematic component that can be estimated. The error term e_i accounts for the nonsystematic component. Similarly, the reported import value M_{ij} is described as:

$$M_{ij} = \alpha_j M^*_{ij} e_j, \tag{3.2}$$

where M_{ij} represents the observed import value (*cif*) reported by the *j*th country imported from the *i*th country. The term α_j represents the "importer bias" coefficient.

In comparing the difference between the actual value of exports X^*_{ij} and the actual value of imports M^*_{ij} for a given transaction, the import value in general would exceed the value of exports because of the presence of the transportation margin. This relationship can be written as a ratio:

$$\frac{M^*_{ij}}{X^*_{ij}} = 1 + g = \gamma. \tag{3.3}$$

Variable g represents the proportion of the *fob* value of exports that is attributable to transportation costs. The term $\gamma > 1$ is equal to the *cif/fob* ratio. A general price rise has no effect on the *cif/fob* ratio because it is expressed in relative terms. The *cif/fob* ratio is another systematic discrepancy between reported imports and exports; however, unlike reporting biases, which are country-specific, this ratio is commodity-specific.

At this point, we have identified three systematic components of the discrepancy between reported imports and exports: exporter bias, importer bias, and the commodity-specific margin. Now combine equations (3.1)–(3.3) into a single equation that describes the relationship between the ratio of reported trade values and the systematic components:

$$\frac{M_{ij}}{X_{ij}} = \frac{\alpha_j e_j}{\beta_i e_i}\gamma. \tag{3.4}$$

Rewriting (3.4) in natural logarithms yields:

$$\ln\frac{M_{ij}}{X_{ij}} = \ln\alpha_j - \ln\beta_i + \ln\gamma + \ln e_j - \ln e_i. \tag{3.5}$$

From equation (3.5) we may estimate the systematic components: α_j, β_i, and γ.

We estimate a dummy-variable model that contains specific indicator variables for each importer and each exporter. A commodity-specific dummy variable is used for each commodity. For every country, we estimate an exporter bias β_j, and an importer bias α_i. Also, a commodity-specific margin γ is estimated. Biased reporting is estimated in the regression model on a relative basis. For example, underreporting is estimated for a specific country when it consistently underreports relative to other countries with which it trades.

The estimated coefficients are used to adjust reported export and import data so that the reconciled data are on a bias-free, *fob* basis. Consistency is achieved by adjusting trade data so that exports equal imports:

$$X_{ij} = M_{ij}. \tag{3.6}$$

Transactions reported by both exporter and importer are referred to as "two-sided" transactions. These are distinguished from transactions for which there is only one value reported (by either the exporter or importer), which are referred to as "one-sided." We use only two-sided transactions in the regression analysis, since the dependent variable is a ratio of the two values.

Our reconciliation procedure is extended such that multiple bias coefficients are estimated for a given reporter. This is useful given the diversity in reporting behavior across commodities for any one country. Having many traded commodities in our data,[4] we recognize that a country can overreport exports for one commodity and underreport exports of another. It is therefore necessary to estimate multiple bias coefficients for each reporting country.

To obtain these alternative bias measures for each country, we apply the model to several subsets of the data containing unique reporting biases. With little *a priori* information on which countries over- or underreport what commodities, it is only through the regression results that differences in reporting patterns are revealed. Once the average reporting biases are estimated, the data are transformed by those biases. In those instances in which this transformation worsens the discrepancy between reported imports and exports, we assume that a different type of bias applies. These "nonconforming" observations are separated out, and a different regression model is applied. This process of data segmentation is repeated several times until a satisfactory degree of conformity is obtained.

Evaluation of the reconciliation of partner statistics

How does reconciliation alter the total value of merchandise trade data? By design, the method adjusts reported values based on "relative" biases for bilateral transactions. This type of adjustment alters the reported totals somewhat for individual reporters. Table 3.2 shows the import totals by region as reported by the importer, the importers' partners, and the reconciled total. For almost all the reporting countries there are only slight changes in the total reported values. Of course, there are cases of *severe* underreporting (or nonreporting) in some countries in the composite regions of Latin America, sub-Saharan Africa, the Middle East and North Africa, and Eastern Europe/Former Soviet Union. In most of these cases, the partners' reported trade was used, after adjusting for the international transport margins.

In the final column of Table 3.2, comparisons are made with International Monetary Fund (IMF) merchandise import totals. Entries report the ratio of the reconciled GTAP value to the IMF value. For the US, Canada, and Australia, the IMF's totals are higher than the GTAP totals. In other individual countries, the GTAP totals are higher than the IMF totals. The largest discrepancy is for China, where the GTAP total is 1.222 times greater than the IMF total. In this case, the GTAP total relied heavily on the partners' reporting of China's exports. We presume that this is due to underreporting of trade flows by China, as well as differences in reporting conventions. In the case of Mexico, the large discrepancy (1.148) may be attributed to differences in reporting practices for the manufacturing plants along the US–Mexico border.

Table 3.3 shows the size of world trade, by GTAP commodity. World merchandise trade is weighted heavily toward finished manufactured goods including transportation equipment and machines. Together, these make up over 45% of the total. Oil, and chemicals, rubber, and plastics also constitute a large share (16%) of total merchandise trade. The presence of certain highly disaggregate commodities (e.g., rice and wool) in this data base reflects the special needs of the Australian Industry Commission, which did much of the original data work underpinning GTAP (Jomini et al. 1991).

Table 3.2. ***Reported and Reconciled Totals of Merchandise Imports by Region (1992 $US million)***

Region	Reported by Importer	Reported by Partner	Reconciled Value	Reconciled/IMF ratio
	(cif value)	*(fob value)*	*(fob value)*	*(fob basis)*
AUS	38,201	32,098	37,997	.931
NZL	8,959	6,200	8,719	1.075
CAN	116,358	106,031	113,495	0.907
US	531,381	407,887	512,032	0.955
JPN	222,922	141,873	217,564	1.096
KOR	79,934	51,840	78,125	1.010
EU	568,296	412,215	558,921	n.a.
IDN	27,069	18,109	27,114	1.024
MYS	n.a.	28,271	33,594	0.927
PHL	12,769	11,406	14,865	1.024
SGP	70,784	42,981	73,088	1.100
THA	39,005	28,749	40,168	1.108
CHN	75,229	46,181	78,706	1.222
HKG	122,389	95,209	120,827	n.a.
TWN	n.a.	56,965	54,545	n.a.
ARG	14,597	12,681	14,269	1.047
BRA	22,601	16,522	24,944	1.212
MEX	47,640	53,645	55,330	1.148
LAM	43,988	72,664	71,836	n.a.
SSA	2,329	32,626	34,464	n.a.
MNA	49,583	129,395	127,816	n.a.
EIT	20,794	39,549	69,831	n.a.
SAS	33,536	25,178	32,250	n.a.
ROW	239,709	231,673	248,502	n.a.

Margins function and estimation

International transportation margins can pose a barrier to trade much the same as do tariffs. In addition, the presence of transport costs typically means that prices are not fully transmitted across geographically separated markets. Most models of international trade do not include trade margins. As a consequence, analyses of the implications of policy shocks for the pattern of international trade are unlikely to be accurate in cases in which substantial margins are involved. The GTAP model has an explicit role for the export of international

Table 3.3. ***Reconciled World Totals of Merchandise Trade by Commodity (1992 $US million)***

Sector	Reconciled (fob value)	Share of Total%
PDR	613	0.02
WHT	12,278	0.46
GRO	11,288	0.43
NGC	57,318	2.16
WOL	4,176	0.16
OLP	12,368	0.47
FOR	7,693	0.29
FSH	26,488	1.00
COL	17,140	0.65
OIL	176,604	6.67
GAS	28,553	1.08
OMN	52,432	1.98
PCR	3,166	0.12
MET	21,082	0.80
MIL	9,139	0.34
OFP	71,072	2.68
B&T	27,763	1.05
TEX	93,936	3.55
WAP	105,610	3.99
LEA	54,849	2.07
LUM	56,237	2.12
PPP	71,811	2.71
P&C	53,650	2.03
CRP	251,252	9.48
NMM	28,961	1.09
I&S	76,664	2.89
NFM	52,426	1.98
FMP	57,192	2.1
TRN	320,245	12.09
OME	781,253	29.49
OMF	105,742	3.99
TOTAL	2,649,002	100.00%

transportation services, and for their use in the bilateral movement of merchandise between regions.

International trade margins vary widely across traded commodities and across routes. Agricultural goods generally have a low value per ton compared to nonagricultural or manufactured goods, thus leading to a higher trade margin. Within the food sector, margins tend to be lower for high-value processed food products and higher for low-value bulk commodities (Gehlhar, Binkley, and Hertel 1991). Variation in margins by route are also caused by differences in the volume shipped and differences in port efficiency. Small ports with lower trade volumes tend to have fewer mechanized facilities, thereby increasing the time for loading and unloading. Therefore, the *fob–cif* margin can vary substantially across ports.

Although it is technically possible to estimate transportation margins based on *fob–cif* values by commodity and route, such data are often reported inconsistently. It is not uncommon to find that the export value reported on an *fob* basis exceeds the corresponding reported import value on a *cif* basis. For this reason, it is useful to estimate a general "margins function" that can be used to produce margins estimates, even when *fob–cif* comparisons are not possible.

For practical reasons, the estimation of a margins function is done independently of the reconciliation phase. However, we use a similar statistical technique. Like the model developed from equation (3.5), the dependent variable is the ratio of the two values (*cif/fob*). Furthermore, we wish to control for reporting biases by individual countries, so the same dummy variables are used to measure reporting biases. However, we also need to add explanatory variables specific to the trade margin. For example, as world freight rates rise, relative to other prices, we would expect a corresponding rise in the trade margin. The variable used for world freight rates is a dry-cargo freight index based on tramp voyage rates for 28 routes (OECD 1964–1987, in *Maritime Transport*). This is an annual freight index constructed to give worldwide coverage. Because this index was published in nominal values, it was deflated by the US consumer price index (CPI) to reflect real changes in freight cost.

Distance in miles also enters our margins function. We expect larger trade margins for longer routes. A Mercator's projection map giving the mileage for various water routes is used to determine the shortest distances from port to port. We also add variables designed to deal with port-specific effects. Estimates of port capacity, by country, would have been ideal; however, this information was unavailable. Furthermore, because countries have multiple ports, and because we do not know where trade leaves/enters the country, we are not able to address this component in our regression model. However, we do have estimates of the volume of trade along specific routes, and we use it as an explanatory variable in the margins function. We expect that the margin will be a decreasing function of the total volume of trade along a given route. Since our trade flows are expressed in value terms (current $US), we deflate the flows in order to obtain a proxy for trade volume.

Recall the relationship between the trade data and the margin:

$$\frac{M^{*}_{kijt}}{X^{*}_{kijt}} = 1 + g = \gamma. \tag{3.7}$$

The terms X^*_{kijt} and M^*_{kijt} represent bias-free reported export and import values from exporter i to importer j, for commodity k, in time period t. We choose the Cobb–Douglas functional form to represent the relationship between this ratio and its arguments:

$$\gamma_{kijt} = \gamma_k D_{ij}^{\theta_D} F_t^{\theta_F} V_{ijt}^{\theta_V}, \tag{3.8}$$

where γ_{kijt} represents the *cif/fob* ratio for commodity k, shipped from i to j in time period t. The γ_k term represents the general ratio over all routes and time periods for commodity k. The variables D_{ij}, F_t, and V_{ijt} represent distance from i to j, world freight rate in time t, and volume of total trade from i to j in time t, respectively. The coefficients θ_D, θ_F, and θ_V are estimated in natural logarithmic forms, yielding:

$$ln\left(\frac{M^*_{kijt}}{X^*_{kijt}}\right) = \gamma_k C_k + \theta_D \ln D_{ij} + \theta_F \ln F_t + \theta_V \ln V_{ijt}. \tag{3.9}$$

Here, C_k is a dummy variable identifying the kth commodity.

Finally, we must deal with the fact that the data are not free of country-specific reporting biases. We correct for this aspect by using individual dummy variables for each importer and exporter. The final margins model is:

$$\begin{aligned} Y_s = \mu &+ \sum_{N-1}^{i=1} \alpha_j C_{is1} - \sum_{N-1}^{i=1} \beta_i C_{is2} + \sum_{K}^{i=1} \gamma_k C_{is3} \\ &+ \theta_D \ln D_{ij} + \theta_F \ln F_t + \theta_{VT} \ln V_{ijt} + e_s. \end{aligned} \tag{3.10}$$

(The notation is simplified by letting $Y_s = \ln (M_{kijt}/X_{kijt})$, where $S = 1 \ldots s$ is an index representing the total number of observations in the entire data set.)

We use the parameter estimates from (3.10) to compute bilateral transportation margins for 1992. In computing margins, we fix the time dimension by holding the world freight rate constant, and we allow distance and traded volumes to change as we move across different routes. The only factor missing from equation (3.8) that must be included is the effect of reporting biases on margins, which we will denote as coefficient A. This coefficient can be summarized as follows:

$$A = e^{\mu} \prod_{i=1}^{N-1} \overline{C}_{i1}^{\alpha_i} \overline{C}_{i2}^{\beta_i}, \tag{3.11}$$

where $\overline{C}_{i1}$ and $\overline{C}_{i2}$ are the samplewide means of the dummy variables, μ is the estimated intercept, and α_i and β_i are the estimated importer and exporter biases. We can now write the bilateral trade margins function as follows:

$$\gamma_{kijt} = \gamma_k A * D_{ij}^{\theta_D} F_t^{\theta_F} V_{ijt}^{\theta_{VT}}]. \tag{3.12}$$

Equation (3.12) is used to generate the *cif/fob* ratio for all commodities and routes.

Table 3.4. ***Exports of Nonfactor Services by Region (1992 $US billions)***

Region	Exports[a]	Imports: Nonshipping	Imports: Shipping[b]
EU[c] [32.08%][d]	234.74 (29.49%)[e]	171.26 (29.21%)	46.47 (22.18%)
US [26.49%]	152.65 (19.18%)	87.66 (14.95%)	36.75 (17.53%)
Japan [17.81%]	73.84 (9.28%)	70.10 (11.96%)	21.10 (10.07%)
Australia [30.57%]	16.49 (2.07%)	9.56n (1.63%)	3.06 (1.46%)
Other East Asia [17.35%]	111.00 (13.95%)	57.24 (9.76%)	40.37 (19.27%)
Latin America [19.51%]	37.51 (4.71%)	33.48 (5.71%)	12.99 (6.20%)
Other regions [20.92%]	169.70 (21.33%)	157.08 (26.79%)	48.82 (23.29%)
World [23.10%]	795.94 (100.00%)	586.37 (100.00%)	209.56 (100.00%)

[a] Includes sbipping services.
[b] Shipping services purchased as part of *cif* merchandise imports.
[c] Excludes EU intraregional trade.
[d] Share of total exports comprising services.
[e] Percentage of total services exports.

Trade in services

Trade in services includes trade in factor services (interest, profits, and dividends) as well as trade in nonfactor services (business, insurance, and financial services). In the GTAP framework we have data only on nonfactor services trade, which is in turn broken into shipping and nonshipping services components. Regional exports of shipping services are available in the UN COMTRADE data base, but trade in nonshipping services is not. Therefore, it must be obtained from alternative sources. The IMF is one of the better sources of this information and was used extensively for obtaining data on trade in services. The 1992 services trade data were assembled on an individual-country basis for total exports and imports. GTAP regional totals were obtained by aggregating individual countries. In doing so, all regional totals of services trade contain intraregional trade, with the exception of the European Union (EU), where it is excluded.[5]

Table 3.4 reports trade in these services, by selected regions. World exports of nonfactor services are reported in the first column. In total, they amount to $795 billion (excluding intra-EU trade). About a third of this (29.49%) comes from the EU. (Parenthetic entries in Table 3.4 refer to the share of each region's nonfactor services exports in the worldwide total.) These exports include both shipping and nonshipping services. The former are obtained from the COMTRADE data base. Since these shipping services exports can be used for transporting goods between any two trading partners, tracking the source and destination of shipping services is not possible. For this reason the GTAP model treats these flows as exports to the "global shipping sector" (see Chapter 2). They are then embodied in the value of merchandise imports *cif* rather than as an individual component of total imports.

Imports of nonfactor services in Table 3.4 are broken into two components: shipping and nonshipping. The shipping component totals $209 billion, and represents the trade margin component of merchandise imports, valued on a *cif* basis. The nonshipping component of nonfactor services amounts to $586 billion. Again, the EU is the dominant trading partner, making up about 29% of this total. Together, the sum of shipping and nonshipping services imports equals total services exports ($795 billion).

Trade in nonshipping, nonfactor services represents a significant component of global trade. The bracketed entries in the left-hand margin of Table 3.4 report the share of these services exports in the regional and world totals. From this, it may be seen that services trade makes up 23.1% of total trade in the GTAP data base, on a worldwide basis. However, this figure is higher for the EU (32%), which supplies a disproportionate share of the world's shipping services.

Having only the totals of nonfactor services trade by individual countries, it was necessary to allocate this total across the six GTAP service sectors (sectors 32–37 in Table 3.1). It would be inappropriate to allocate total services equally across all sectors. Some service sectors are largely "nontradeable" services; naturally, their share of total traded services is small. These sectors electricity, water and gas (32), construction (33), and ownership of dwellings (37). The sectoral shares used to make the allocation were obtained from the original country IO tables. In the case of countries for which the IO data shares were missing, we used the average shares for all reporting countries.

Once the sectoral allocation of nonfactor, nonshipping services was made, these totals were bilateralized among trading partners. The bilateral pattern of services trade is not available on a global basis. We approximate the bilateral trade patterns for services based on bilateral merchandise trade patterns. Solving this problem entails satisfying the sectoral services totals of individual countries (for both imports and exports) while preserving the initial bilateral merchandise share coefficients. This is not possible. Therefore a constrained matrix balancing algorithm was adopted.[6] This minimizes the deviation between the final trade shares and the initial shares while satisfying the sectoral total values. Bilateral trade patterns for all six service sectors were obtained independently by this method. One consequence of this approach is that only countries that trade with one another in merchandise trade will trade in services, and the proportions are roughly the same. Further work is needed in order to establish a more reliable pattern of trade in nonfactor services.

In order to balance world trade, total exports of all goods and services must be equal to total imports of all goods and services. Therefore, the difference between *cif* imports and *fob* exports must equal the value of shipping services. This is summarized as follows:

Total merchandise imports (*cif*) +Nonshipping services		Total merchandise exports (*fob*) +Nonshipping services +Shipping services
Total imports	=	Total exports

III Support and protection data

This section documents the support and protection data (SPD) in GTAP. Our goal is to make the process followed in developing these data transparent to users of GTAP. This will help users become aware of the advantages and limitations of this part of the data base, thereby informing the choice and implementation of the simulations that are ultimately done.

One of the first points to be made is that the SPD are not comprehensive. Some of the limitations will be addressed in the coming years, but others never will nor could be. While there are gaps in the coverage of industries, and policy types, the only sector that is wholly neglected is the services sector. Protection of and support to the service sector are especially difficult to quantify. This does not mean, of course, that the sector is without distortions or that these distortions are unimportant, as the attention given the sector during the Uruguay Round has suggested.

The best-quality data in the SPD are those relating to tariffs. As will be detailed below, the information is systematically aggregated up from extremely detailed tariff line information, using bilateral import weights. The resulting bilateral rates therefore reflect compositional differences in the tariff/trade structure. Nontariff information is most complete in the cases of agriculture and textiles/wearing apparel. However, antidumping duties are also incorporated for Canada, the EU, and the US. Also, the export restraining effects of EU price undertakings are included.

Other trade measures, despite their importance, are very difficult to quantify in a useful way.[7] Some studies that have focused on particular industries in particular countries have usefully quantified nontariff measures. However, data used in disaggregated multicountry general equilibrium models have not accurately and comprehensively incorporated most other nontariff measures. In developing the SPD it was thought better to do a solid job of incorporating tariff and selected nontariff, information and to leave other policy measures aside for the time being, given the dubious information content of the latter.

Despite the several missing pieces to the protection puzzle mentioned in the above paragraphs, we would not be inclined to use, for a general set of problems, any other existing data base over this one. Although these data are incomplete, others are lacking in important areas or, still worse, are misleading. Given the first-order importance that initial distortions play in any quantitative analysis of trade policies, we welcome an increased focus on trade policy measurement.[8]

Individual-country tariffs

The tariff data used in the protection data base draw on the original country submissions to the GATT for the Uruguay Round. The data vary by year reported, reporting tariff code, level of aggregation, and number of line items. For each tariff line item in each country file, there are data on (1) the value of total imports, (2) bilateral import values from the 17 other GTAP countries, and (3) three different tariff rates: most favored nation (MFN), generalized system of preferences (GSP), and the tariff rates actually applied. The latter applied rates reflect the tariffs charged at the time of file submission, and may be lower than the ceiling rate at which the tariff is bound (MFN rate).

Tariff rates faced by different exporters may vary for a variety of reasons. Discriminatory rates could result from regional trade agreements, the presence of GSP rates for lower-income countries (usually limited to particular commodities), and an importer's refusal to grant MFN status to a particular exporter. It would be desirable to include discriminatory tariff rates in the protection data. Yet some economists argue that implicit discrimination, operating through the composition of trade in developed countries' tariff schedules, far outweighs in importance such discriminatory tariff practices as the GSP and preferential trading arrangements. In the GTAP data base we have chosen to focus on bilateral variation due to compositional differences in trade.

Tariff schedules for most countries contain between 5,000 and 10,000 tariff lines and product classifications.[9] Empirical trade policy models necessarily incorporate trade policies based on aggregations of these tariff lines. Bilateral tariffs at the GTAP level of aggregation were constructed by aggregating *applied* tariff rates from the tariff lines to the GTAP sectors using bilateral import value weights. As noted above, this can result in significant differences in aggregated tariff rates for the same GTAP commodity imported from different sources. For example, imports from developing countries may be mostly primary or semiprocessed goods, while imports from developed countries may be mostly processed goods. If tariff rates vary with the stage of processing, as they often do, then the average tariff within an aggregate faced by developing countries will differ in a systematic way from that faced by developed countries.

Table 3.5. ***Comparison of Simple Average Tariffs to Weighted Average Tariffs***

Importer	Indonesia	United States	Australia	New Zealand
Industry	Nongrain Crops (4)	Beverages and Tobacco (17)	Textiles (18)	Chemicals, Rubber, and Plastics (24)
Simple average	17.1	8.0	25.4	14.0
Minimum	0.0	0.0	0.0	0.0
Maximum	40.0	338.0	115.0	524.0
Std. dev.	11.7	17.4	18.1	21.8
Trade weighted average	3.9	4.3	13.2	19.8
Bilateral Weighted Averages				
Argentina	2.2	5.3	14.0	5.0
Australia	0.9	2.7	n.a.	23.3
Brazil	3.4	15.8	4.2	22.2
Canada	24.1	2.3	26.7	11.8
China	7.8	2.6	12.3	20.0
EU	10.4	4.5	16.9	18.1
Hong Kong	3.5	5.1	12.3	24.7
Indonesia	n.a.	3.1	10.3	31.8
Japan	6.3	3.2	7.6	20.2
Korea, S.	11.4	2.4	6.9	25.4
Malaysia	12.4	1.1	13.2	36.0
Mexico	0.0	6.8	17.0	13.5
New Zealand	10.3	0.5	23.3	n.a.
Philippines	5.1	2.4	29.4	12.4
Singapore	12.0	0.8	9.4	19.8
Taiwan	3.4	4.3	12.2	27.6
Thailand	9.8	5.2	11.2	23.3
US	2.9	n.a.	16.9	17.1
ROW	1.7	2.5	10.5	19.1

Given the Armington framework (product differentiation by region of origin) adopted in the GTAP, the incorporation of bilateral average tariff rates means that each trade flow can be subject to a unique tariff rate. Table 3.5 gives four examples comparing simple average tariffs and bilateral weighted average tariffs. The bilateral weighted averages can be above or below the simple average tariffs, depending on the composition of imports. In most cases, the simple average overstates the average constructed using total trade weights (compare the first row in Table 3.5 to the fifth row), but the case of chemicals, rubber, and plastics trade in New Zealand illustrates that this generalization does not always hold.

The bottom portion of Table 3.5 reports bilateral, trade-weighted average applied tariffs for these four cases. Differences in these rates reflect the interaction between variation in tariff line rates and bilateral trade flows. In each case, some tariff lines are free of tariffs while others are quite high (524% is the maximum applied rate for chemicals, rubber, and plastics imports in New Zealand). For example, from the first column in Table 3.5 it is clear that these compositional considerations discriminate most heavily against Canadian nongrain crop sales to Indonesia. In contrast, the nongrain crops shipped by Australia to Indonesia face almost no tariffs (on average).

Several steps were involved in calculating GTAP tariff rates.[10] The first step was to create a rest of the world (ROW) import value in order to generate a single trade-weighted tariff for exports from the 6 composite regions in the GTAP data base. The ROW import value is equal to the total import value less the import values from the other 17 countries. This means that there is no bilateral variation in the individual-country GTAP tariffs vis-à-vis the 6 composite regions. Each country file was then aggregated to the GTAP level to create the bilateral trade-weighted average tariffs for each country file.

The first 18 columns of Table 3.6 report the weighted average bilateral tariffs levied by the each of the GTAP regions for all merchandise trade. (The last 6 columns correspond to composite region tariffs that derive from a different source, discussed below.) Just as we observed at the individual commodity level in Table 3.5, Table 3.6 shows that there remains considerable bilateral variation in the applied tariff rates, aggregated over all merchandise trade. Thus the average tariff on *all* merchandise imports into Canada from New Zealand is 2.9%, whereas imports from Hong Kong are subjected to an average tariff of 15.2%. In other words, Hong Kong exports to Canada involve products with relatively high tariff rates. In general, the highest average tariffs in this table are levied by the Philippines, Thailand, China, Argentina, and Brazil.

The last 6 *rows* of these first 18 *columns* in Table 3.6 correspond to imports into the 18 individual GTAP countries from the 6 composite regions. As noted above, these share a common tariff rate at the 37-sector, GTAP level of aggregation, because they are trade-weighted averages using a common, ROW import level. However, once these tariffs are aggregated up from the 37-sector GTAP level, they, too, exhibit significant bilateral variation. For instance, Middle East and North African exports to New Zealand (mostly oil) face an average bilateral tariff of 1.8%, whereas the average tariff on imports from South Asia (much of this, textiles and other light manufactures) is over 20%.

Finally, note that it is possible to use the aggregation methodology outlined above for aggregation of detailed tariff *offers*, such as those submitted under

Table 3.6. *Average Bilateral Applied Tariff Rates for All Merchandise Trade*

(Percentage of cif values)

	AUS	NZL	CAN	US	JPN	KOR	EU	IDN
AUS	0.0	15.0	5.3	4.3	1.7	10.5	2.5	5.3
NZL	10.7	0.0	2.9	2.3	5.1	11.8	3.8	11.3
CAN	14.3	18.4	0.0	3.2	3.1	9.9	4.8	5.5
US	15.9	23.1	7.1	0.0	3.1	16.5	4.2	12.1
JPN	18.9	32.2	7.6	5.2	0.0	18.3	9.1	14.3
KOR	17.8	23.0	9.8	6.1	6.9	0.0	7.1	18.0
EU	15.4	21.8	8.9	4.5	7.1	18.0	0.0	16.2
IDN	8.9	17.3	9.2	7.5	3.2	9.3	7.9	0.0
MYS	13.8	15.6	7.6	4.4	2.6	12.2	7.1	12.3
PHL	14.8	25.7	11.9	8.7	5.1	14.1	10.0	10.8
SGP	16.1	42.3	6.3	3.8	5.2	20.1	9.7	11.0
THA	8.5	13.6	9.2	6.6	6.1	15.6	8.2	9.7
CHN	19.8	35.0	12.7	6.2	7.0	14.4	5.9	11.1
HKG	17.1	34.5	15.2	11.1	6.8	20.5	10.2	18.9
TWN	15.2	28.0	8.5	5.9	8.2	19.2	7.2	18.9
ARG	9.2	6.7	8.5	5.1	4.7	21.4	10.0	3.9
BRA	15.3	19.8	8.3	5.6	3.4	13.5	6.7	10.8
MEX	10.3	12.2	6.8	4.0	1.6	12.2	2.6	11.0
LAM	10.3	5.5	3.1	4.5	2.8	7.1	6.6	4.1
SSA	4.1	3.2	1.3	1.1	3.2	6.2	3.9	5.8
MNA	5.7	1.8	1.6	2.0	0.6	5.7	2.8	1.4
EIT	13.5	20.6	6.8	5.1	3.3	14.6	5.5	8.4
SAS	10.1	20.8	16.2	10.3	3.9	12.6	8.6	6.8
ROW	19.4	24.2	5.0	4.3	3.8	13.4	5.7	10.3

the Uruguay Round negotiations. The policy shocks to be implemented in the model may then be derived by differencing the two bilateral tariff matrices. Analyzing policy shocks using two sets of tariffs, both of which have been aggregated up from the original tariff line items, more accurately captures the policy change. This is particularly true when a tariff cutting formula is nonlinear. For instance, early in the Kennedy Round, the European Community proposed a tariff cutting plan under which tariffs on manufactured products would be reduced by 50% of the difference between existing rates and 10%.[11] Current practice in most modeling exercises involves simply applying the formula to a model's aggregated tariffs. However, due to variation in the disaggregated tariffs (see the standard deviations in Table 3.5), it is much

Table 3.6. ***Average, Bilateral Applied Tariff Rates for all Merchandise Trade***

(Percentage of cif values)

	MYS	PHL	SGP	THA	CHN	HKG	TWN	ARG
AUS	3.8	17.3	1.1	21.0	24.4	0.0	3.8	15.5
NZL	3.8	16.1	0.1	27.0	16.0	0.0	8.1	19.8
CAN	6.3	18.3	0.0	25.1	12.7	0.0	3.7	23.4
US	7.2	21.7	0.1	33.1	16.4	0.0	7.8	24.5
JPN	9.6	23.8	0.2	36.9	34.3	0.0	5.9	22.0
KOR	9.1	23.6	1.6	34.9	29.9	0.0	6.7	25.7
EU	9.1	26.4	0.1	35.3	38.8	0.0	8.1	17.5
IDN	9.1	23.6	0.6	34.2	22.2	0.0	3.5	26.4
MYS	0.0	22.6	1.2	38.7	29.4	0.0	4.7	16.6
PHL	10.6	0.0	0.3	41.6	26.5	0.0	4.8	26.9
SGP	8.1	22.1	0.0	27.5	28.1	0.0	7.5	30.3
THA	12.9	24.7	0.4	0.0	25.7	0.0	5.9	24.3
CHN	5.4	22.3	0.2	31.9	0.0	0.0	5.7	29.1
HKG	10.3	29.8	0.5	28.1	41.5	0.0	11.1	21.6
TWN	13.8	30.2	0.2	42.7	38.9	0.0	0.0	30.8
ARG	6.4	27.3	0.0	22.4	18.0	0.0	5.4	0.0
BRA	6.0	18.6	0.0	15.1	23.9	0.0	4.0	26.6
MEX	5.5	21.3	0.3	31.3	21.1	0.0	0.0	19.6
LAM	7.3	12.1	2.7	37.4	16.9	0.0	4.0	24.3
SSA	7.0	29.9	0.4	16.3	23.6	0.0	6.2	24.3
MNA	1.9	19.7	1.0	25.7	5.8	0.0	4.3	18.8
EIT	5.4	15.5	1.3	21.1	14.6	0.0	6.8	20.3
SAS	9.5	18.2	1.0	19.1	16.7	0.0	4.9	29.4
ROW	9.8	19.6	0.3	31.3	19.2	0.0	6.1	21.8

preferable to apply the formula to the original country tariff submission data and then reaggregate to find the new tariff rates at the 37-sector level of aggregation. This approach was used in a GTAP analysis of the Uruguay Round offers conducted in conjunction with the US International Trade Commission and the World Bank.

Composite region tariffs

Tariff data for the six composite regions were supplied by the International Economics Division of the World Bank. Due to the large number of countries involved, and the limited data availability for many of these countries, *representative* countries were used for each of the composite regions. The particular

Table 3.6. *Average, Bilateral Applied Tariff Rates for all Merchandise Trade*

(Percentage of cif values)

	BRA	MEX	LAM	SSA	MNA	EIT	SAS	ROW
AUS	8.1	9.3	11.0	7.4	7.4	8.5	9.2	9.3
NZL	30.7	12.6	13.4	10.9	11.9	9.8	5.8	9.3
CAN	17.7	10.7	9.7	10.4	10.0	10.7	9.9	9.5
US	21.7	10.3	11.4	10.8	10.8	11.5	9.9	10.8
JPN	50.9	14.1	13.1	12.9	12.6	11.9	12.1	12.7
KOR	46.3	12.0	13.5	13.8	12.4	13.2	11.6	12.3
EU	45.8	13.1	10.7	10.8	10.6	10.7	9.6	10.6
IDN	32.6	12.4	11.2	10.2	11.5	7.4	9.4	10.0
MYS	38.6	12.9	10.8	9.6	10.1	11.8	9.2	10.8
PHL	32.4	16.0	11.3	9.1	11.7	11.4	11.9	11.6
SGP	34.2	13.7	5.2	7.2	9.6	9.1	7.0	9.0
THA	25.4	14.0	11.6	11.6	11.4	11.5	11.5	11.9
CHN	18.4	13.2	11.6	11.7	11.4	10.3	11.3	10.9
HKG	45.4	16.8	16.2	16.0	15.7	15.4	15.7	14.8
TWN	38.3	6.0	14.4	13.6	13.9	14.7	12.8	14.4
ARG	39.3	8.3	11.1	12.5	12.5	11.9	11.1	11.6
BRA	0.0	13.4	10.9	11.3	11.4	11.1	11.0	10.9
MEX	23.6	0.0	9.1	10.4	4.7	11.4	10.0	8.3
LAM	19.9	10.0	12.3	11.8	12.4	11.2	10.7	11.5
SSA	2.9	12.4	10.9	8.2	7.2	8.0	8.1	9.2
MNA	4.9	9.5	5.9	5.8	6.4	3.9	3.5	3.6
EIT	24.4	9.5	11.6	8.8	9.0	6.4	6.7	7.1
SAS	45.2	11.2	12.7	11.3	11.5	12.0	10.9	13.0
ROW	33.4	11.8	10.2	10.8	10.5	10.4	10.0	10.4

countries used are given in Table 3A.1, in the appendix at the end of this chapter. In several cases, tariff data were available, but bilateral import data were not. In the cases of Algeria and Saudi Arabia, bilateral data from similar countries within the region were used. In the case of sub-Saharan Africa (which excludes South Africa), no trade data were available and so a composite of total import data from other developing countries was used to weight the tariffs prior to aggregation.

The composite region tariffs are listed in the last six columns of Table 3.6. These rates fall in the midrange of the full table. They are higher than tariffs in the Canada, US, Japan, and the EU, but not as high as in many of the other

Magee methodology is a simple way of reducing the downward bias that otherwise exists in average tariff calculations.[14] The final step was to aggregate across exporters for those orders affecting exporting countries in the composite GTAP regions, such as the EU.[15] This was calculated as an unweighted average of the duties found using the Magee methodology above.

The Canadian AD duties included in the 1994 GTAP data base are based on 88 AD orders in force as of June 30, 1993.[16] (See Table 3.8.) Each of these orders refers to a particular commodity being exported from a particular country, and AD duties imposed by Canada generally apply to all firms exporting from that country. The estimated average margin of dumping determined by the Canadian authorities for these orders was 33.3%, with some as high as 87%. These orders are found in 13 GTAP sectors and on 15 GTAP regions, and they are weighted by their coverage ratios before aggregation to the GTAP concordance. At the GTAP sector level, the resulting duties are under 10% in most cases. Exceptions include nongrain crops from the US, with a duty of almost 30%, and pulp and paper, for which the AD duties on imports from the 12 GTAP regions covered by orders are between 10 and 20% for most exporters.

United States AD duties are applied on a firm-specific basis. Products of firms from the same exporting country accused of dumping the same product often are assessed different AD duties, and often an "all other firms" rate is introduced that is applied against exports of other firms. This creates special problems in describing the magnitude of AD duties in effect, as firm-specific trade data that could be used to aggregate these duties are not normally available. Therefore, for any one order we calculated the duty as the midpoint of the highest and lowest AD duties assigned the various firms.[17] The AD duties of the US are based on 266 AD orders in effect as of December 31, 1992 (Table 3.8). The average of the estimated duties prior to aggregation is 45%. The US duties cover portions of 15 GTAP sectors and 15 GTAP regions. As in Canada, most of the aggregated duty rates are under 10%. Notable exceptions are chemical, rubber, and plastic imports from Japan (24%), machinery and equipment imports from Japan (31%), and primary ferrous metals imports from Brazil and Taiwan (19% and 12%, respectively).

The AD measures included in the database for the EU include both AD duties and price undertakings resulting from AD cases, based on orders in effect as of December 31, 1992. These orders include 42 undertakings, 85 duties, and 35 orders with both undertakings and duties. The average margin for the 162 AD actions that enter the database is 30%. The orders include AD duties in 9 GTAP sectors and 13 GTAP regions and price undertakings in 10 GTAP sectors and 13 GTAP regions. Price undertakings are incorporated into the database as export tax equivalents so that the economic rents resulting from the undertakings are properly allocated to the exporters. The most

Table 3.8. ***Summary of Antidumping Duties***

Importer	Number of Orders Covered	Date	Estimated Average Margin	Number of GTAP Sectors	Number of GTAP Exporters
Canada	88	June 30, 1993	33%	13	15
EU	162	December 31, 1992	30%	10	13
US	266	December 31, 1992	45%	15	15

Table 3.11. *Output Subsidies for Farm and Food Sectors (percentage of market values)*

	AUS	NZL	CAN	US	JPN	KOR	EU	IDN	MYS	PHL	SGP	THA
Paddy rice	3.7	0.0	0.0	57.3	10.1	50.5	7.2	4.7	0.0	-2.1	0.0	2.3
Wheat	4.1	2.7	16.8	32.4	14.8	-0.3	6.3	0.0	0.0	-2.2	0.0	0.0
Grains (other than rice & wheat)	3.6	1.9	7.6	30.6	16.4	8.1	2.5	10.6	0.0	-2.1	0.0	-0.3
Nongrain crops	2.2	-0.8	10.3	5.2	48.9	36.7	71.0	1.9	0.0	-2.4	-1.8	0.4
Wool	3.3	2.0	3.5	63.0	0.0	-0.1	0.4	0.0	0.0	-0.8	0.0	0.0
Other livestock	1.3	1.5	4.7	3.5	0.5	14.8	9.2	-0.5	0.0	-1.8	-2.1	-0.1
Processed rice	-0.7	0.0	-0.4	-0.4	0.0	-0.2	0.0	-1.0	0.0	-0.7	0.0	-1.4
Meat products	-0.7	-0.7	21.9	-0.3	-1.3	-1.6	0.2	-0.8	0.0	-2.2	-1.4	-0.8
Milk products	-5.7	0.8	4.5	4.3	7.2	19.9	-0.4	-1.1	0.0	-4.4	-0.6	-3.1
Other food products	-0.9	-0.3	-0.4	-0.5	-0.8	-5.8	0.0	-1.2	0.0	-2.0	-0.7	-1.5
Beverages & tobacco	-1.0	-0.5	-1.5	-18.8	-46.4	-52.3	-2.5	-14.7	0.0	-13.9	-0.4	-41.2

Table 3.11. *Output Subsidies for Farm and Food Sectors (percentage of market values)*

	CHN	HKG	TWN	ARG	BRA	MEX	LAM	SSA	MNA	EIT	SAS	ROW
Paddy rice	-0.9	0.0	-1.1	0.0	45.6	1.3	152.1	-71.1	-11.7	127.1	6.2	-1.4
Wheat	-1.0	0.0	-0.7	0.0	24.9	2.7	47.8	-7.6	145.6	-14.0	-4.4	12.7
Grains (other than rice & wheat)	-2.5	0.0	0.0	0.0	28.1	4.2	161.3	-1.9	42.7	21.3	-15.5	26.1
Nongrain crops	-4.1	0.0	-0.7	0.0	0.5	1.0	-27.3	9.7	36.0	49.8	2.9	142.4
Wool	-0.8	0.0	0.0	0.0	0.5	0.0	0.0	-0.6	-1.5	-0.8	-0.8	-0.9
Other livestock	-0.9	0.0	-0.1	0.0	5.9	-0.1	1.0	-0.8	-0.7	28.6	1.0	-0.4
Processed rice	-4.6	0.0	-0.2	0.0	-0.2	3.9	-1.0	-3.2	-0.9	-0.9	-4.6	-0.8
Meat products	-2.5	0.0	-2.1	0.0	0.0	-0.1	-0.8	-1.9	-1.1	-0.2	-2.5	-0.6
Milk products	-7.4	0.0	-1.2	0.0	-0.1	-0.1	-2.2	-3.9	-2.8	13.5	12.7	-0.4
Other food products	-3.6	0.0	-1.1	0.0	0.4	3.8	-1.5	-2.5	-2.4	-0.5	-3.6	-0.7
Beverages & tobacco	-23.6	0.0	-54.8	0.0	-0.4	-21.2	-31.5	-20.9	-36.0	-19.2	-23.6	-33.4

detailed commodity basis, for the period 1986–1990. Country submissions were then examined by other Uruguay Round participants for methodology and accuracy prior to completion of the Uruguay Round at Marrakesh in mid-April 1994. This and other such information became public at that time.

The Uruguay Round schedules for the base export subsidy outlays form the basis for the agricultural export subsidies in the GTAP data base. Export subsidies are recorded on the GATT schedules for 6 countries (counting the EU as one), and for as many as 20 agricultural commodities in any one country. These subsidies are reported in Table 3.9, based on GTAP commodity categories. Canada, the US, and the EU are the major users of this form of subsidy, with the EU expending over $10 billion (in 1992 dollars) on exports subsidies for grain, dairy, and meat products.

Import Nontariff Barriers (NTBs). Table 3.10 reports import barriers in the data base for the 11 farm and food sectors and the 24 GTAP regions. Asterisks denote wedges that include information from the PSE data base in the form of world/domestic price gaps. Where this information is available, one would assume that the size of this gap exceeds any tariff that may be present. However, we adopt the simple rule of taking the *larger* of the two distortions. Table 3.10 represents the tariff/NTB data base after it is combined in this manner. The most striking entries are for grain imports into Japan and Korea, where quotas have sustained an extremely high level of domestic prices relative to world prices. Dairy products also exhibit a great deal of protection across many of the economies.

Output subsidies. As noted above, much of the support for agriculture comes in the form of subsidies on input usage or on output. Both these types of support are combined into a single output subsidy. Of course, in some regions (e.g., sub-Saharan Africa) producers receive less than the market value of their produce, and this is reflected in an output tax. In the case of the composite regions, output subsidies were derived from PSE data for a subset of the countries in each region. Appendix Table 3A.2 lists the countries for which this information was available in each of the six composite regions. Finally, where PSE data are not available, we simply use the indirect tax rate reported in the input–output table.

The GTAP output subsidies for farm and food products are reported in Table 3.11. Entries represent the subsidy (or tax in the case of negative numbers) as a percentage of market values. Note that in some cases (Malaysia and Hong Kong) there is no tax at all. This is because these countries are not represented in the PSE data base and their IO tables do not report indirect taxes for these sectors. The Philippines is not represented in the PSE data base but it does include indirect taxes in its IO table, so all of the sectors experience a small negative subsidy (i.e., a tax). The largest producer subsidies occur for grains in North and South America, and in the economies in transition [Eastern Europe and the Former Soviet Union (FSU)]. In the latter case, these subsidies may well have changed dramatically in recent years. This is a problem that each GTAP user must come to grips with based on its individual needs. For example, it may be appropriate to adjust protection levels prior to proceeding with policy analysis.

Other commodity taxes. In some cases the IO tables also include a variety of commodity taxes. We leave these in place, but do not report on them here, as they are generally sparse and quite small as a percent of market value. However, we encourage the GTAP user to examine these tax rates when they receive an aggregation of the data base, as they may play some role in determining second-best outcomes.

Effective rates of protection. One useful means of summarizing the profile of combined protection measurers, by region, is the effective rate of protection (ERP), which is obtained by comparing value-added at domestic market and world prices, using the same factor proportions. Stevens (1995) has developed a formula for calculating ERPs in the GTAP data base, based on a composite measure of import and export protection, as follows:

$$TC(i,r) = \gamma(i,r) * TM(i,r) + [1 - \gamma(i,r)] * TX(i,r), \tag{3.13}$$

where $\gamma(i,r) = VDM(i,r) / [VDM(i,r) + VXM(i,r)]$ is the ratio of domestic sales of merchandise commodity i, produced in region r, to total (domestic and export) sales, at market prices. $TM(i,r)$ and $TX(i,r)$ are the power of the *ad valorem* rates of import (both tariff and NTB) and export protection, respectively. Therefore, an import tariff ($TM(i,r) > 1$) is represented as supporting the price of domestic sales, but not exports, and vice versa for an export subsidy ($TX(i,r) > 1$).

Stevens applies these composite border support measures to output and intermediate inputs, by sector, to obtain value-added at world prices as follows:

$$VAW(j,r) = VOM(j,r) / TC(j,r) - \sum_{i \in TRAD} VFM(i,j,r) / TC(i,r). \tag{3.14}$$

Value-added at market prices, $VAM(j,r)$, is computed from (3.14) by setting $TC(i,r) = 1 \ \forall i$. She then computes the sectoral ERP as:

$$ERP(j,r) = [VAM(j,r) - VAW(j,r)] / VAM(j,r). \tag{3.15}$$

Note that this is not the same formula as that in the literature, where $VAW(j,r)$ appears in the denominator. The conventional formulation causes problems when $VAW(j,r)$ becomes negative, as is the case for some (j,r) pairs in the data base.

Table 3.12. ***Effective Rates of Protection for GTAP Data Base by Sector and Region***

	BRA	MEX	LAM	SSA	MNA	EIT	SAS	ROW
PDR	0.17	0.11	0.14	0.03	0.02	-0.04	0.01	0.03
WHT	-0.10	0.10	0.09	0.05	-0.12	0.09	0.08	0.04
GRO	0.19	0.20	0.24	0.11	0.14	0.15	0.03	0.15
NGC	0.16	0.02	0.07	0.07	0.10	0.11	0.09	0.16
WOL	0.21	0.01	0.03	-0.02	0.06	0.07	0.02	0.04
OLP	0.06	-0.01	0.09	0.12	0.10	0.12	0.10	0.12
FOR	0.15	0.10	0.05	0.00	0.01	0.04	0.00	0.04
FSH	0.27	0.21	0.07	0.06	0.06	0.07	0.03	0.04
COL	-0.46	0.06	0.14	0.00	0.15	0.02	0.12	0.05
OIL	-0.14	0.00	0.01	-0.01	0.00	0.00	0.01	0.00
GAS	-0.07	0.04	0.11	-0.02	0.01	-0.01	-0.02	0.00
OMN	-0.04	0.05	0.03	0.00	0.04	0.12	0.01	0.05
PCR	0.59	0.10	0.20	1.07	0.88	0.29	0.36	0.91
MET	0.62	0.24	0.24	0.29	0.22	0.21	0.02	0.18
MIL	0.85	0.29	0.24	0.22	0.25	0.28	0.64	0.25
OFP	0.83	0.03	0.14	0.16	0.22	0.21	0.41	0.20
B_T	0.28	0.17	0.06	0.05	0.05	0.07	0.00	0.06
TEX	0.58	0.18	0.18	0.19	0.17	0.17	0.14	0.15
WAP	0.56	0.19	-0.01	0.05	0.01	0.05	-0.30	0.07
LEA	0.55	0.20	0.10	0.11	0.14	0.12	0.08	0.13
LUM	0.33	0.16	0.17	0.12	0.23	0.18	0.19	0.17
PPP	0.00	0.03	0.12	0.14	0.16	0.15	0.12	0.11
P_C	0.01	0.46	0.09	0.07	0.11	0.16	0.05	0.18
CRP	0.35	0.09	0.09	0.13	0.10	0.12	0.14	0.10
NMM	0.52	0.18	0.18	0.18	0.21	0.16	0.16	0.18
I_S	0.41	0.06	0.11	0.12	0.15	0.11	0.12	0.12
NFM	0.35	0.06	0.01	0.06	0.14	0.08	0.15	0.12
FMP	0.52	0.12	0.18	0.19	0.18	0.17	0.18	0.16
TRN	0.15	0.12	0.15	0.12	0.17	0.15	0.16	0.12
OME	0.38	-0.02	0.12	0.13	0.12	0.12	0.14	0.09
OMF	0.70	0.10	0.17	0.15	0.15	0.17	0.17	0.12

in the *exporting region*, the ERP measure for the importing region (e.g., textiles in the US) does not reflect this intervention. Despite the presence of these export restraints, it is interesting that most textile ERPs are positive. However, because the tax equivalents tend to be higher for wearing apparel than for textiles, the apparel sector shows some significant negative entries for heavily restricted exporters, despite the importance of textiles as an input (e.g., –2.29 for Indonesia).

In sum, there are many different components of protection in the GTAP data base. Not all of them work in the same direction. Stevens's modified ERP measure provides a useful summary of some of their interactions. However, as she also documents in her thesis, the ERP is an imperfect predictor of the effects of trade policy reform, and therefore does not offer a substitute for well-defined simulation experiments.

IV Input–output tables

Input–output tables were obtained for the latest available reference year. (This section covers both work done originally for the SALTER model and new work for the GTAP.[18]) These reference years ranged from 1980 to 1987 (see Table 3.12). We follow Hambley (1993) in adopting the following target format for the IO data:

- An intermediate input matrix for domestic use of domestically produced commodities
- An intermediate input matrix for domestic usage of imports
- Industry payments to land, labor, and capital services
- Final demands for domestically produced commodities by private households and the government, and for gross fixed capital formation,
- Final demands for imported commodities by private households and the government, and for gross fixed capital formation
- Taxes

We begin this stage with a collection of IO tables for various countries, expressed in various currencies and representing different years. The tables come from diverse sources, and differ widely in structure, layout, and sectoral detail. A summary of sources and reference years is provided in Table 3.13. By the end of this stage we have a collection of tables with a consistent structure and sectoral classification, ready to be updated to a common base year.

Besides these formal requirements, we impose some conditions on the content of the tables. We eliminate negative flows, and impose a sectoral balance condition whereby each sector's sales and costs are equal (where profits are counted in with costs). We also make some minor adjustments to avoid technical problems in later processing.

Data structure

Import detail. Following the lead of the SALTER effort, the GTAP data structure provides for full import use information. In other words, it tracks the value of import usage for each individual commodity in each individual use category. In order to appreciate the importance of import-sourcing by use,

Table 3.13. ***Sources of Input-Output Data***

Region	Reference Period	Source
Australia	1986–87	Kenderes and Strzelecki (1992)
New Zealand	1986–87	Department of Statistics (1991), New Zealand
Canada	1986	Statistics Canada (1987)
United States	1985	Ministry of International Trade and Industry (1989), Japan
Japan	1985	Ministry of International Trade and Industry (1989), Japan
Korea	1985	Bank of Korea (1988)
European Union	1980	Ryan (1992)
Indonesia	1985	Central Bureau of Statistics, Indonesia
Malaysia	1983	Department of Statistics (1988), Malaysia
Philippines	1985	National Economic and Development Authority (1988) Philippines
Singapore	1983	Department of Statistics (1987), Singapore
Thailand	1985	Institute for Developing Economies, Tokyo and Soci[illegible] Economic Policy and Forecasting Unit, Chulahlong[illegible]rn University Social Research Institute, Thailand
China (PRC)	1987	Department of Balances of National Economy of [illegible] State Statistical Bureau and Office of the National Input–Output Survey (1987), China
Hong Kong	1988	Tormey (1993)
Taiwan	1986	Directorate General of Budget, Accounting and Statistics (1986), Taiwan
Argentina	1984	Secretaria de Planificacion (1986), Argentina
Brazil	1980	Sectretaria de Planejamento e Coordenacao da Presidencia da Republica Fundacao IBGE (1980), Brazil
Mexico	1985	Secretaria de Pramacion y Presupuesto (1985), Burfisher, Thierfelder, and Hanson (1992)
Rest of Latin America	1992	Representative composite
S-S. Africa	1992	Representative composite
M.E. and North Africa	1992	Representative composite
E. Europe and FSU	1992	Representative composite
South Asia	1992	Representative composite
Regions not Elsewhere Classified	1992	Representative composite

it is instructive to consider a specific example, taken from version 2 of the data base. Table 3.14 reports the share of imports in composite demand, by commodity and use for the Korean economy.[19] For ease of exposition, the 37 sectors have been aggregated up to 12 sectors/commodities. The information in this table is based on the 1985 Korean IO table (see Table 3.13), updated to 1992 macroeconomic and trade data using the procedures described below.

Examination of Table 3.14 shows clearly that the intensity of imports of any given commodity varies widely by use. For example, the last column shows that 22% (value-based share) of all chemical, rubber, and plastic (CRP) products used in Korea is imported. However, only 3% of private household

Table 3.14. ***Share of Imports in Composite Demand at Market Prices, by Use***

	Intermediate Uses												Final Demands			Total Uses
	crops	othagr	extract	food	textiles	apparel	crp	metals	trnseq	macheq	othmnfc	svces	Inv	Priv	Gov	
crops	0.06	0.00	0.51	0.35	0.99	0.49	0.99	0.52	0.76	0.67	0.81	0.00	0.01	0.07	0.14	0.39
other agr.	0.10	0.79	0.54	0.08	1.00	0.99	0.36	0.72	0.86	0.09	0.57	0.13	0.90	0.31	0.77	0.25
extraction	0.00	0.00	0.51	0.21	0.03	0.03	0.48	0.40	0.20	0.27	0.21	0.10	0.01	0.06	0.08	0.28
food	0.00	0.00	0.10	0.26	0.04	0.83	0.58	0.00	0.10	0.03	0.38	0.03	0.26	0.02	0.08	0.06
textiles	0.03	0.01	0.18	0.04	0.17	0.27	0.14	0.05	0.12	0.11	0.06	0.02	0.14	0.04	0.22	0.17
apparel	0.05	0.01	0.18	0.01	0.01	0.80	0.51	0.01	0.40	0.01	0.25	0.01	0.32	0.06	0.62	0.07
crp	0.05	0.00	0.24	0.15	0.14	0.17	0.39	0.18	0.31	0.23	0.23	0.07	0.08	0.03	0.09	0.22
metals	0.19	0.04	0.10	0.08	0.11	0.25	0.09	0.21	0.23	0.24	0.14	0.07	0.23	0.19	0.07	0.19
transport eq	0.00	0.00	0.09	0.00	0.00	0.00	0.01	0.04	0.42	0.20	0.17	0.35	0.17	0.01	0.15	0.22
mach. & eq.	0.02	0.02	0.32	0.18	0.40	0.15	0.46	0.45	0.36	0.54	0.28	0.34	0.55	0.15	0.14	0.47
other mnfc.	0.10	0.01	0.08	0.41	0.57	0.54	0.24	0.23	0.39	0.67	0.28	0.42	0.23	0.44	0.66	0.36
services	0.01	0.01	0.05	0.03	0.02	0.06	0.06	0.02	0.04	0.05	0.04	0.13	0.01	0.03	0.00	0.04
all goods	0.04	0.03	0.39	0.27	0.38	0.27	0.36	0.21	0.27	0.36	0.21	0.14	0.17	0.04	0.00	0.18

Source: GTAP data base, aggregation of version 2.

purchases of CRP products is sourced from abroad, while 39% of the own-intermediate inputs used by the CRP sector is purchased from overseas. This means that a tariff reduction in this sector will have little direct effect on consumer prices. The first-round effect will be predominantly through lower input costs to firms. Furthermore, the intensive use of imported CRP intermediates by the CRP sector itself will somewhat blunt the effect of competition from more competitive imports.

The last row in Table 3.14 reports the average variation in import intensity, by use. Here it can be seen that, on average, the firms use imports relatively more intensively than do households. Indeed, the average import intensity of private household consumption is only 4%. This stands in sharp contrast to many of the productive sectors, where average import intensities across all intermediate purchases is between 35% and 40% in the cases of extractive industries, textiles, CRP, and machinery and equipment. Even investment goods are more heavily import-oriented than are consumer goods, with an average intensity of 17%. All this information is lost in the bulk of the multiregion AGE data bases in which imports are blended at the border. In such cases, the implicit import intensity is equal across all uses, and is given by the entries in the final column of Table 3.14.

While this detailed breakdown of intermediate and final import usage is available in many published IO tables, other source tables provide less than full information: some give imports by commodity but not by use, others by use but not commodity. Those IO tables with less than full import detail present a special problem; we need somehow to transport this partial information into the full information structure.

In those cases where the IO tables do not provide sufficient information on the breakdown of commodity demands, we assume that the commodity-specific import share of composite commodity demand is uniform across use categories. So, for instance, while the import share for oil may differ from the import share for iron and steel, across all the different sectors that use oil, the oil import share is assumed to be the same. This permits us to share out total imports of a given commodity across intermediates and final demands. We consider this assumption more realistic for narrowly defined commodities than for broadly defined commodities. So where the source data are highly disaggregated, we transport the import information from the partial to the full information data structure before aggregating commodities to the GTAP classification.

The uniform import share assumption lets us generate full import information given source statistics for imports by commodity. The source IO tables provide imports by use category; however, we go to an outside source for imports by commodity. The outside source is the GTAP trade data base described above. In these cases, we must employ an iterative matrix balancing

6. This was accomplished using the Generalized Algebraic Modeling System (GAMS) software (Brooke, Kendrick, and Meeraus 1988), which is designed to solve such problems efficiently. In this case, the objective function minimized the squared deviations between the initial trade share coefficients and final share coefficients such that merchandise trade patterns were imposed on the services trade patterns.
7. The term *useful* here is taken to mean specifically the applicability for inclusion into an economic modeling framework. There exists, for example, a quite comprehensive data base that describes the number and type of nontariff measures by country and industry. Some researchers have, in fact, used the number of nontariff measures in an industry as an indication of the measures' distortionary impact. Readers with an interest in this area should consult Laird and Yeats (1990).
8. It is heartening to learn that the Organization for Economic Cooperation and Development (OECD) is considering undertaking the calculation of effective rates of protection for member countries, rates that would, wherever possible, include the impact of both tariff and nontariff measures.
9. Under the HS, participating countries have harmonized tariff schedules to the first 6 digits. For many products, tariffs are collected based on 8-digit or even 10-digit classifications. The HS contains 5,019 lines at the 6-digit level.
10. Taiwan is an exception to the above process of creating country files. Taiwan gave a tariff file to the GATT for accession purposes, but it was in a format different from GATT member files. The file used for the GTAP data base is based on one created by the US Trade Representatives (USTR) Office from the original Taiwanese file. From this file, it was possible to create bilateral weighted average rates only for the US, Japan, and the EU; all other bilateral rates were filled in with a constructed ROW weighted average rate. About 40 of the tariff line items were blank in the USTR file because specific duties were not converted to *ad valorem* equivalents and were deleted when constructing the weighted averages. The tariff rates reflect those in effect in 1992, although the trade values used were three-year averages from 1989–1991. The rates used were those received by the US–that is, reciprocal rates if they exist, and general rates otherwise.
11. The tariff negotiations of the Kennedy Round are the topic of Baldwin (1965).
12. Personal communication with Yongzheng Yang.
13. Price undertakings require a price increase on the part of the exporter; therefore, price undertakings are reported here as export taxes. For those orders that resulted in both duties and undertakings, half of the resulting margin was allocated as an import duty and half was allocated as an export tax. The aggregation of export taxes resulting form price undertakings was carried out in the same manner as the aggregation of the duties, as explained below.
14. The Magee approach is designed to yield a bias-free welfare loss estimate of a tariff or other duty.
15. Both Canada and the US normally consider EU member states separately for antidumping investigations.
16. Based on GATT, *Trade Policy Review: Canada*, 1995. For information on the operation of the antidumping regimes of Canada, the EU, and the US, consult Finger (1993), Jackson and Vermulst 1989), and the GATT *Trade Policy Review* of each country.
17. At first this appears to be a neutral assumption. However, as there is reason to believe that firms with the largest exports are being assessed the highest duties, we believe this method understates the actual impact of the orders.
18. Brown, Strzelecki, and Watts (1993); Calder, McDougall, and Strzelecki (1993); and Hambley (1993), are important background materials.

19. See Hertel, Ianchovichina, and McDonald (1996) for elaboration of this example. They use a modified version of the GTAP data base to analyze the impact of the Uruguay Round on Korea.
20. This trade imbalance results in a very large negative rate of savings. Therefore, we recommend users aggregate Hong Kong with one or more of its major trading partners in GTAP applications using this version of the data base. We will address this problem in the future data releases.

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CHAPTER 4

GTAP behavioral parameters

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I Introduction and overview

This chapter documents the parameters that specify marginal behavior in the Global Trade Analysis Project (GTAP) model. These behavioral parameters, along with the theory of the model as described in Chapter 2 and the composition of the benchmark data (i.e., the value flows described in Chapter 3), will determine simulation results. No individual component can be said to be more important than the others. For some simulations, it is the accounting identities that determine results, whereas the behavioral parameters may play a relatively small role. For other simulations, the specification of certain elasticities is of paramount importance. Documentation of these elasticities is the purpose of this chapter.

In section II, we discuss the behavioral parameters at the disaggregate 37-commodity, 24-region level. Most behavioral parameters in GTAP are based on constant elasticity specifications [e.g., the constant elasticity of substitution (CES) function], which simplify model calibration. However, consumer behavior in GTAP is based on the constant difference elasticity (CDE) function, of which the CES is a special case. Because this has not been widely used in applied general equilibrium (AGE) modeling to date, we provide a brief overview and motivation for the CDE in section III of this chapter. We then discuss the calibration and performance of the CDE demand system.

II Disaggregate behavioral parameters

There are four types of behavioral parameters in GTAP: elasticities of substitution (in both consumption and production), transformation elasticities that determine the degree of mobility of primary factors across sectors, the flexibilities of regional investment allocation, and consumer demand elasticities. We begin with the elasticities of substitution that determine the conditional price responsiveness of the nested-CES utility and production functions.

Table 4.1: GTAP Substitution Elasticities

	Value-Added (σ_{VA})	Domestic/Imported (σ_D)	Sourcing of Imports(σ_M)
Paddy rice (PDR)	0.56	2.2	4.4
Wheat (WHT)	0.56	2.2	4.4
Grains (other than rice and wheat: GRO)	0.56	2.2	4.4
Nongrain crops (NGC)	0.56	2.2	4.4
Wool (WOL)	0.56	2.2	4.4
Other livestock (OLP)	0.56	2.8	5.6
Forestry (FOR)	0.56	2.8	5.6
Fishing (FSH)	0.56	2.8	5.6
Coal(COL)	1.12	2.8	5.6
Oil (OIL)	1.12	2.8	5.6
Gas (GAS)	1.12	2.8	5.6
Other minerals (OMN)	1.12	2.8	5.6
Processed rice (PCR)	1.12	2.2	4.4
Meat products (MET)	1.12	2.2	4.4
Milk products (MIL)	1.12	2.2	4.4
Other food products (OFP)	1.12	2.2	4.4
Beverages and tobacco (BT)	1.12	3.1	6.2
Textiles (TEX)	1.26	2.2	4.4
Wearing apparel (WAP)	1.26	4.4	8.8
Leather, etc. (LEA)	1.26	4.4	8.8
Lumber and wood (LUM)	1.26	2.8	5.6
Pulp, paper, etc. (PPP)	1.26	1.8	3.6
Petroleum and coal products (PC)	1.26	1.9	3.8
Chemicals, rubber and plastics (CRP)	1.26	1.9	3.8
Nonmetallic mineral products (NMM)	1.26	2.8	5.6
Primary ferrous metals (IS)	1.26	2.8	5.6
Nonferrous metals (NFM)	1.26	2.8	5.6
Fabricated metal products nec. (FMP)	1.26	2.8	5.6
Transport Equipment (TRN)	1.26	5.2	10.4
Machinery and equipment (OME)	1.26	2.8	5.6
Other manufacturing (OMF)	1.26	2.8	5.6
Electricity, water, and gas (EGW)	1.26	2.8	5.6
Construction (CNS)	1.4	1.9	3.8
Trade and transport (TT)	1.68	1.9	3.8
Other services (private) (OSP)	1.26	1.9	3.8
Other services (government) (OSG)	1.26	1.9	3.8
Ownership of dwellings (DWE)	1.26	1.9	3.8

Source: Jomini *et al.*, table 4.3, 1991.

Elasticities of substitution

The SALTER Project engaged in an extensive review of the literature and some original empirical work to specify values for substitution elasticities on a *commodity-specific, region-generic* basis (Jomini et al. 1991). Because we have adopted the SALTER commodity concordance, it was quite natural also to adopt SALTER substitution elasticity values. Instead of attempting to refine these values further, we have chosen to focus our efforts on other problems. However, estimation and validation of these substitution elasticities is an important priority for future work.

The first column of Table 4.1 reports the elasticities of substitution, σ_{VA}, in the value-added aggregates for each of the GTAP sectors. The overall elasticity of substitution among primary factors determines the ability of the economy to alter its output mix in response to changes in relative commodity prices. These parameters also play an important role in determining sectoral supply response, in the presence of sector-specific and sluggish factors of production. For example, with the supply of agricultural land fixed in the model, the ability to expand farm output can be directly linked to the ease of substitution of labor and capital for land. Note that the relatively small elasticity of substitution in primary production means that aggregate agricultural supply response is somewhat limited. When capital is treated as a sluggish factor of production, this elasticity of substitution plays the same role in capital using sectors. The greatest degree of substitutability (1.68) arises in the trade and transport sector.

Table 4.1 also reports the elasticities of substitution σ_D, and σ_M for the Armington structure in GTAP. The first value, σ_D, describes the ease of substitution between the domestic good and the composite import, by commodity. As such, it governs the composite import demand elasticity. The second Armington parameter, σ_M, determines the case of substitution among imports from different sources. In the SALTER parameter file, this is equal to twice the value of σ_D. This is an empirical regularity, reported in Jomini et al. (1991), which considerably simplifies the task of parameterizing a multiregion trade model. In the absence of additional information, it probably also makes sense to preserve this relationship when conducting systematic sensitivity analysis on the Armington structure.

Mobility parameters

The second type of behavioral parameters in GTAP relate to primary factor mobility. Within each region, the model distinguishes between primary factors that are perfectly mobile across productive sectors and those factors that are sluggish (see also Chapter 2). In an experiment with sluggish endowment commodities, it is important to determine *how much of a disparity in relative sectoral returns can be sustained over the simulation period.* This disparity is governed by the elasticity of transformation, $\sigma_T < 0$, for sluggish endowment commodities. If σ_T is close to zero, then the allocation of factors across uses is nearly fixed and unresponsive to changes in relative returns. As σ_T takes on more negative values, then the supply of factors to various uses becomes more and more responsive to relative returns [see equation (51) in Table 2.14 of Chapter 2]. In the limit, as $\sigma_T \rightarrow -\infty$, this factor is perfectly mobile and no differential return can be sustained over the time horizon envisioned in the simulation. If this is the case, then the factor in question should be reclassified into the set of mobile endowment commodities.

Flexibilities of regional investment

In addition to the elasticity of transformation for endowment commodities, there is another set of "mobility" parameters that determine the flexibility of regional investment. If the GTAP user chooses to allow the allocation of global investment to regional economies to respond to region-specific rates of return on capital (i.e., parameter *RORDELTA* is 1), then parameter *RORFLEX*(*r*) > 0 must be properly specified [equation (58) of Table 2.15 in Chapter 2]. The smaller the *RORFLEX*(*r*), the greater the responsiveness of international investment to a change in the rate of return in region *r*. Because *RORFLEX*(*r*) is indexed over regions, it is possible to have some regions where investment is quite sensitive to changing rates of return, and others where this is not the case.

Consumer demand elasticities

The parameters that describe demand behavior in initial equilibrium for the representative private household are *region-specific*. Consumer behavior in GTAP is based on the CDE expenditure function, which is most naturally calibrated to income and own-price elasticities of demand (Hertel et al. 1991). We obtained information on income elasticities of demand from three sources: a world food model recently estimated by the Food and Agriculture Organization (1993), the SALTER model (Jomini et al. 1991), and Theil, Chung, and Seale (1989). Using these income elasticities, we derived own-price demand elasticities based on a linear expenditure system (LES) relationship (Frisch 1959). As discussed in the next section, the CDE is a more flexible functional form than the LES, and we could have used independent information on own-price demand elasticities in this calibration exercise. However, deriving own-price elasticities from the income elasticities and the Frisch parameter provided a useful starting point for establishing consistent own-price effects. In the future, we hope to supplement the elasticities file with cross-country studies of own-price responses. In addition, by using the CDE, GTAP modelers are given the flexibility to adjust commodity-specific substitution effects to conform with outside information on own-price elasticities of demand for key commodities in any particular application.

For agricultural and food commodities we draw upon the Food and Agriculture Organization (FAO) model (FAO 1993), which has excellent country coverage and has proved to be a good source for recent estimates of income elasticities. Some comments on the way we used the FAO income elasticities follow:

- We considered 0.1 as the lower bound for income elasticities because smaller values can cause calibration problems for the CDE.
- For the European Union (EU), we used FAO estimates for Germany because the EU has not been identified as a single region in the FAO model.

- Elasticities for the 6 composite regions were computed in all cases as a weighted sum of elasticities for the 18 individual GTAP regions (see Chapter 3 for a discussion of these weights).
- The region "China" in the FAO model covers both the PRC and Taiwan. We applied the FAO estimates for China to both GTAP regions.
- For "other grains" we used FAO elasticities for maize or other coarse grains (otherwise the lower bound of 0.1 was applied).
- The income elasticities employed for "meat products" were linear averages of the FAO values for beef, pork, chicken, and lamb.
- For "other food products" we computed a linear average of FAO elasticities for butter and oils.
- The elasticity applied to "processed rice" was set equal to twice the value employed for "paddy rice" in each region because processed products typically have higher income elasticities of demand than their raw counterparts.
- The income elasticities employed for "textiles and wearing apparel" have been taken from Theil and colleagues (1989) and then reduced by one half to be applied to "wool and other agricultural products."

For nonagricultural, and nonfood commodities, we used income elasticities from the SALTER model and Theil, Chung, and Seale (1989). In particular, we used SALTER elasticities for the regions common to both GTAP and SALTER. Values for countries in the Association of South East Asian Nations (ASEAN) region of SALTER have been applied to Indonesia, Malaysia, Philippines, Singapore, and Thailand in GTAP. The ASEAN values were also applied to China and Taiwan in the GTAP. For Hong Kong, Argentina, and Brazil we used estimates from Theil and colleagues. Values for Mexico were computed as a linear average of those applied to Argentina and Brazil. Table 4.2 presents income elasticities of demand chosen for the GTAP data. Engel aggregation does not hold for all regional income elasticities in Table 4.2. We impose this condition in the calibration phase by proportionally adjusting all income elasticities.

Values for own-price elasticities of demand were computed following the procedure outlined in Zeitsch et al. (1991) for own-price elasticities of demand (Frisch 1959):

$$\varepsilon_{ii} = -s_i\eta_i\left(1 + \frac{\eta_i}{\omega}\right) + \frac{\eta_i}{\omega}, \tag{4.1}$$

where ε_{ii} is the uncompensated own-price demand elasticity for commodity i; η_i is the income elasticity of demand for commodity i, s_i is the expenditure

Table 4.2. ***GTAP Income Elasticities of Demand***

	AUS	NZL	CAN	US	JPN	KOR	EU	IDN	MYS	PHL	SGP	THA
PDR	0.20	0.10	0.20	0.20	0.10	0.30	0.20	0.50	0.20	0.20	0.30	0.10
WHT	0.10	0.10	0.10	0.10	0.10	0.30	0.10	1.00	0.31	0.50	0.10	0.50
GRO	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.17	0.20	0.10	0.10
NGC	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
WOL	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48
OLP	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48
FOR	1.15	1.17	1.10	1.09	1.12	1.19	1.13	1.23	1.23	1.23	1.23	1.23
FSH	1.15	1.17	1.10	1.09	1.12	1.19	1.13	1.23	1.23	1.23	1.23	1.23
COL	1.15	1.17	1.10	1.09	1.12	1.19	1.13	1.23	1.23	1.23	1.23	1.23
OIL	1.15	1.17	1.10	1.09	1.12	1.19	1.13	1.23	1.23	1.23	1.23	1.23
GAS	1.15	1.17	1.10	1.09	1.12	1.19	1.13	1.23	1.23	1.23	1.23	1.23
OMN	1.15	1.17	1.10	1.09	1.12	1.19	1.13	1.23	1.23	1.23	1.23	1.23
PCR	0.40	0.20	0.40	0.40	0.20	0.60	0.40	1.00	0.40	0.40	0.60	0.20
MET	0.30	0.11	0.27	0.13	0.70	0.78	0.33	0.86	0.36	0.66	0.56	0.40
MIL	0.10	0.10	0.10	0.10	0.50	1.07	0.10	1.34	0.38	0.50	0.40	0.54
OFP	0.20	0.25	0.17	0.15	0.75	0.83	0.17	0.97	0.74	0.92	0.58	0.93
B_T	0.94	0.96	0.90	0.89	0.89	0.86	0.90	0.83	0.83	0.83	0.83	0.83
TEX	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96
WAP	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96
LEA	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96
LUM	1.15	1.17	1.10	1.09	1.12	1.19	1.13	1.23	1.23	1.23	1.23	1.23

Table 4.2. ***GTAP Income Elasticities of Demand***

	AUS	NZL	CAN	US	JPN	KOR	EU	IDN	MYS	PHL	SGP	THA
PPP	1.15	1.17	1.10	1.09	1.12	1.19	1.13	1.23	1.23	1.23	1.23	1.23
P_C	1.15	1.17	1.10	1.09	1.12	1.19	1.13	1.23	1.23	1.23	1.23	1.23
CRP	1.15	1.17	1.10	1.09	1.12	1.19	1.13	1.23	1.23	1.23	1.23	1.23
NMM	1.15	1.17	1.10	1.09	1.12	1.19	1.13	1.23	1.23	1.23	1.23	1.23
I_S	1.15	1.17	1.10	1.09	1.12	1.19	1.13	1.23	1.23	1.23	1.23	1.23
NFM	1.15	1.17	1.10	1.09	1.12	1.19	1.13	1.23	1.23	1.23	1.23	1.23
FMP	1.15	1.17	1.10	1.09	1.12	1.19	1.13	1.23	1.23	1.23	1.23	1.23
TRN	1.07	1.09	1.03	1.01	1.03	1.03	1.04	1.01	1.01	1.01	1.01	1.01
OME	1.07	1.09	1.03	1.01	1.03	1.03	1.04	1.01	1.01	1.01	1.01	1.01
OMF	1.07	1.09	1.03	1.01	1.03	1.03	1.04	1.01	1.01	1.01	1.01	1.01
EGW	1.15	1.17	1.10	1.09	1.12	1.19	1.13	1.23	1.23	1.23	1.23	1.23
CNS	1.15	1.17	1.10	1.09	1.12	1.19	1.13	1.23	1.23	1.23	1.23	1.23
T_T	1.15	1.16	1.10	1.08	1.11	1.17	1.12	1.20	1.20	1.20	1.20	1.20
OSP	1.16	1.18	1.11	1.09	1.14	1.23	1.14	1.29	1.29	1.29	1.29	1.29
OSG	1.15	1.17	1.10	1.09	1.12	1.19	1.13	1.23	1.23	1.23	1.23	1.23
DWE	1.15	1.17	1.10	1.09	1.12	1.19	1.13	1.23	1.23	1.23	1.23	1.23

Table 4.2. ***GTAP Income Elasticities of Demand***

	CHN	HKG	TWN	ARG	BRA	MEX	LAM	SSA	MNA	EIT	SAS	ROW
PDR	0.25	0.20	0.25	0.10	0.20	0.30	0.20	0.23	0.20	0.17	0.25	0.15
WHT	0.30	0.40	0.30	0.10	0.40	0.40	0.43	0.34	0.38	0.44	0.30	0.17
GRO	0.10	0.10	0.10	0.10	0.10	0.10	0.11	0.12	0.11	0.11	0.10	0.10
NGC	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
WOL	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48
OLP	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48
FOR	1.23	1.27	1.23	1.33	1.32	1.33	1.27	1.24	1.20	1.28	1.23	1.14
FSH	1.23	1.27	1.23	1.33	1.32	1.33	1.27	1.24	1.20	1.28	1.23	1.14
COL	1.23	1.27	1.23	1.33	1.32	1.33	1.27	1.24	1.20	1.28	1.23	1.14
OIL	1.23	1.27	1.23	1.33	1.32	1.33	1.27	1.24	1.20	1.28	1.23	1.14
GAS	1.23	1.27	1.23	1.33	1.32	1.33	1.27	1.24	1.20	1.28	1.23	1.14
OMN	1.23	1.27	1.23	1.33	1.32	1.33	1.27	1.24	1.20	1.28	1.23	1.14
PCR	0.50	0.40	0.50	0.20	0.40	0.60	0.41	0.46	0.41	0.34	0.50	0.29
MET	0.67	0.38	0.67	0.18	0.55	0.41	0.51	0.64	0.49	0.49	0.67	0.47
MIL	0.75	0.54	0.75	0.10	0.40	0.47	0.56	0.66	0.60	0.46	0.75	0.35
OFP	0.85	0.58	0.85	0.54	0.82	0.79	0.85	0.85	0.72	0.86	0.85	0.56
B_T	0.83	1.02	0.83	1.02	1.02	1.02	0.92	0.85	0.86	0.93	0.83	0.90
TEX	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96
WAP	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96
LEA	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96

Table 4.2. *GTAP Income Elasticities of Demand*

	CHN	HKG	TWN	ARG	BRA	MEX	LAM	SSA	MNA	EIT	SAS	ROW
LUM	1.23	1.27	1.23	1.33	1.32	1.33	1.27	1.24	1.20	1.28	1.23	1.14
PPP	1.23	1.27	1.23	1.33	1.32	1.33	1.27	1.24	1.20	1.28	1.23	1.14
P_C	1.23	1.27	1.23	1.33	1.32	1.33	1.27	1.24	1.20	1.28	1.23	1.14
CRP	1.23	1.27	1.23	1.33	1.32	1.33	1.27	1.24	1.20	1.28	1.23	1.14
NMM	1.23	1.27	1.23	1.33	1.32	1.33	1.27	1.24	1.20	1.28	1.23	1.14
I_S	1.23	1.27	1.23	1.33	1.32	1.33	1.27	1.24	1.20	1.28	1.23	1.14
NFM	1.23	1.27	1.23	1.33	1.32	1.33	1.27	1.24	1.20	1.28	1.23	1.14
FMP	1.23	1.27	1.23	1.33	1.32	1.33	1.27	1.24	1.20	1.28	1.23	1.14
TRN	1.01	1.26	1.01	1.31	1.31	1.31	1.14	1.03	1.03	1.17	1.01	1.05
OME	1.01	1.26	1.01	1.31	1.31	1.31	1.14	1.03	1.03	1.17	1.01	1.05
OMF	1.01	1.26	1.01	1.31	1.31	1.31	1.14	1.03	1.03	1.17	1.01	1.05
EGW	1.23	1.27	1.23	1.33	1.32	1.33	1.27	1.24	1.20	1.28	1.23	1.14
CNS	1.23	1.27	1.23	1.33	1.32	1.33	1.27	1.24	1.20	1.28	1.23	1.14
T_T	1.20	1.27	1.20	1.33	1.32	1.33	1.25	1.21	1.18	1.27	1.20	1.13
OSP	1.29	1.27	1.29	1.33	1.32	1.33	1.30	1.29	1.24	1.31	1.29	1.16
OSG	1.23	1.27	1.23	1.33	1.32	1.33	1.27	1.24	1.20	1.28	1.23	1.14
DWE	1.23	1.27	1.23	1.33	1.32	1.33	1.27	1.24	1.20	1.28	1.23	1.14

share of commodity i; and ω is the Frisch parameter, that is, minus the reciprocal of the marginal utility of income, or the money flexibility.

The values chosen for ω were taken from Zeitsch et al. (1991) for the SALTER regions in GTAP. For the other regions in GTAP the following values were employed: (1) for China and Taiwan $\omega = -5$; (2) for Hong Kong $\omega = -4$; (3) for Argentina, Brazil, and Mexico $\omega = -3$; and (4) for the six composite regions we used weighted average values of ω based on known regions in GTAP (see Chapter 3 for the relevant weights). The subsequent values for the uncompensated own price elasticities of demand, based on the GTAP data set, are reported in Table 4.3. To calibrate the CDE expenditure function, we need compensated elasticities, ν_{ii}, which can be derived as follows:

$$\nu_{ii} = \varepsilon_{ii} + s_i\eta_i. \tag{4.2}$$

III CDE private household preferences

This section discusses the specification of consumption demands for the private household in GTAP. This involves three issues: choosing a functional form for the underlying utility or expenditure function, selecting values for income and price elasticities of demand (discussed in the previous section), and calibrating the model to income and price elasticities. The functional form chosen must satisfy theoretical restrictions and be analytically tractable, and the elasticity values should be consistent with empirical evidence. The first restriction means that we have to choose a functional form from the family of well-known functions: Cobb–Douglas, constant elasticity of substitution (CES), linear expenditure system (LES) (Stone 1954), constant ratios of elasticities homothetic (CRESH) (Hanoch 1971), the translog, and others.

A Cobb–Douglas utility function implies unitary uncompensated own-price and income elasticities. This property is not supported by empirical evidence and it would lead to biased results for many AGE simulations. The CES relaxes the assumption of unitary uncompensated own-price elasticities, but its income elasticities are unitary, since, like the Cobb–Douglas, it is a homothetic utility function. A homothetic utility function implies that average household budget shares spent on various commodities are independent of total expenditures.[1] Such a property is hard to justify given the evidence that, for example, the share of food expenditures tends to decline with total expenditures. For example, the US spends less than 10% on food, and Israel spends about 25% (Putnam and Allshouse 1993, p. 139).

The LES of demand equations is based on the Klein–Rubin utility function (Klein and Rubin 1948–1949), which represents nonhomothetic preferences; therefore, its income elasticities are not unitary. However, its marginal budget shares are constant with respect to the level of expenditure.[2] This property is

Table 4.3. ***GTAP Own Price Elasticities of Demand***

	AUS	NZL	CAN	US	JPN	KOR	EU	IDN	MYS	PHL	SGP	THA
PDR	-0.1370	-0.0398	-0.1026	-0.1081	-0.0405	-0.0926	-0.0966	-0.0964	-0.0412	-0.0381	-0.0571	-0.0191
WHT	-0.0685	-0.0398	-0.0513	-0.0541	-0.0405	-0.0926	-0.0484	-0.2022	-0.0593	-0.0953	-0.0190	-0.0953
GRO	-0.0685	-0.0398	-0.0513	-0.0541	-0.0405	-0.0309	-0.0484	-0.0201	-0.0326	-0.0385	-0.0191	-0.0191
NGC	-0.0695	-0.0405	-0.0523	-0.0546	-0.0415	-0.0361	-0.0489	-0.0298	-0.0204	-0.0233	-0.0241	-0.0224
WOL	-0.3288	-0.1913	-0.2462	-0.2595	-0.1943	-0.1482	-0.2319	-0.0914	-0.0914	-0.0914	-0.0914	-0.0914
OLP	-0.3306	-0.1920	-0.2471	-0.2600	-0.1950	-0.1508	-0.2353	-0.0982	-0.0985	-0.0969	-0.1043	-0.1025
FOR	-0.7877	-0.4662	-0.5649	-0.5894	-0.4534	-0.3691	-0.5464	-0.2386	-0.2352	-0.2363	-0.2344	-0.2481
FSH	-0.7882	-0.4662	-0.5642	-0.5893	-0.4563	-0.3797	-0.5467	-0.2599	-0.2715	-0.2971	-0.2425	-0.2559
COL	-0.7877	-0.4663	-0.5641	-0.5893	-0.4534	-0.3792	-0.5465	-0.2343	-0.2343	-0.2343	-0.2343	-0.2343
OIL	-0.7878	-0.4662	-0.5641	-0.5892	-0.4535	-0.3673	-0.5463	-0.2343	-0.2344	-0.2343	-0.2359	-0.2343
GAS	-0.7877	-0.4662	-0.5662	-0.5892	-0.4535	-0.3673	-0.5464	-0.2348	-0.2382	-0.2379	-0.2343	-0.2343
OMN	-0.7877	-0.4662	-0.5642	-0.5893	-0.4534	-0.3673	-0.5460	-0.2343	-0.2344	-0.2356	-0.2344	-0.2345
PCR	-0.2742	-0.0797	-0.2052	-0.2163	-0.0830	-0.2051	-0.1935	-0.2875	-0.0835	-0.0966	-0.1159	-0.0430
MET	-0.2097	-0.0459	-0.1425	-0.0720	-0.2900	-0.2586	-0.1692	-0.1857	-0.0776	-0.1525	-0.1103	-0.0981
MIL	-0.0698	-0.0408	-0.0528	-0.0548	-0.2050	-0.3385	-0.0500	-0.2568	-0.0792	-0.1022	-0.0802	-0.1064
OFP	-0.1447	-0.1118	-0.0937	-0.0855	-0.3450	-0.3232	-0.0895	-0.2237	-0.1761	-0.2744	-0.1386	-0.2191
B_T	-0.6597	-0.3966	-0.4722	-0.4902	-0.3792	-0.3003	-0.4516	-0.1953	-0.1874	-0.1995	-0.1707	-0.1922
TEX	-0.6620	-0.3948	-0.4960	-0.5211	-0.3921	-0.3042	-0.4782	-0.1922	-0.2072	-0.1903	-0.2332	-0.1972
WAP	-0.6638	-0.3953	-0.5067	-0.5293	-0.4063	-0.3168	-0.4716	-0.1855	-0.1953	-0.1968	-0.2101	-0.2419
LEA	-0.6601	-0.3871	-0.4957	-0.5216	-0.3924	-0.2992	-0.4687	-0.1847	-0.1841	-0.1856	-0.2025	-0.1920
LUM	-0.7902	-0.4729	-0.5690	-0.5922	-0.4557	-0.3702	-0.5534	-0.2400	-0.2408	-0.2388	-0.2484	-0.2399

Table 4.3. *GTAP Own Price Elasticities of Demand*

	AUS	NZL	CAN	US	JPN	KOR	EU	IDN	MYS	PHL	SGP	THA
PPP	-0.7907	-0.4775	-0.5713	-0.5949	-0.4576	-0.3740	-0.5521	-0.2373	-0.2482	-0.2373	-0.2478	-0.2363
P_C	-0.7961	-0.4787	-0.5734	-0.6006	-0.4566	-0.3703	-0.5634	-0.2562	-0.2725	-0.2461	-0.2655	-0.2436
CRP	-0.7926	-0.4836	-0.5726	-0.5972	-0.4673	-0.3989	-0.5568	-0.2550	-0.2938	-0.2672	-0.2683	-0.2688
NMM	-0.7881	-0.4674	-0.5652	-0.5897	-0.4546	-0.3686	-0.5477	-0.2353	-0.2374	-0.2353	-0.2355	-0.2376
I_S	-0.7877	-0.4662	-0.5641	-0.5923	-0.4535	-0.3673	-0.5462	-0.2343	-0.2344	-0.2348	-0.2344	-0.2344
NFM	-0.7877	-0.4663	-0.5641	-0.5892	-0.4544	-0.3673	-0.5464	-0.2343	-0.2344	-0.2343	-0.2394	-0.2343
FMP	-0.7888	-0.4689	-0.5652	-0.5902	-0.4549	-0.3693	-0.5476	-0.2365	-0.2380	-0.2358	-0.2391	-0.2362
TRN	-0.7401	-0.4544	-0.5500	-0.5633	-0.4260	-0.3246	-0.5152	-0.2041	-0.2621	-0.1957	-0.1965	-0.2045
OME	-0.7406	-0.4557	-0.5428	-0.5547	-0.4303	-0.3402	-0.5113	-0.2037	-0.2920	-0.2069	-0.2708	-0.2180
OMF	-0.7355	-0.4427	-0.5331	-0.5504	-0.4225	-0.3242	-0.5073	-0.1944	-0.2040	-0.1958	-0.2311	-0.2044
EGW	-0.7932	-0.4807	-0.5786	-0.6058	-0.4711	-0.3806	-0.5551	-0.2430	-0.2544	-0.2500	-0.2499	-0.2453
CNS	-0.7877	-0.4673	-0.5645	-0.5892	-0.4535	-0.3673	-0.5502	-0.2343	-0.2343	-0.2348	-0.2343	-0.2371
T_T	-0.8563	-0.6135	-0.7065	-0.7073	-0.6260	-0.4946	-0.6392	-0.4829	-0.3916	-0.4614	-0.4793	-0.5117
OSP	-0.8149	-0.5710	-0.6311	-0.7299	-0.6482	-0.4960	-0.6990	-0.3788	-0.2992	-0.3071	-0.3316	-0.3723
OSG	-0.8132	-0.5232	-0.5800	-0.6419	-0.5052	-0.4236	-0.5610	-0.2651	-0.2546	-0.2701	-0.2632	-0.2602
DWE	-0.8307	-0.5575	-0.6580	-0.5894	-0.4538	-0.4235	-0.6031	-0.2353	-0.2966	-0.3046	-0.2578	-0.2348

Table 4.3. *GTAP Own Price Elasticities of Demand*

	CHN	HKG	TWN	ARG	BRA	MEX	LAM	SSA	MNA	EIT	SAS	ROW
PDR	-0.0619	-0.0500	-0.0500	-0.0333	-0.0669	-0.1000	-0.0512	-0.0716	-0.0527	-0.0423	-0.0614	-0.0561
WHT	-0.0660	-0.1000	-0.0617	-0.0333	-0.1333	-0.1333	-0.1077	-0.0724	-0.0983	-0.1102	-0.0658	-0.0660
GRO	-0.0254	-0.0250	-0.0202	-0.0334	-0.0334	-0.0348	-0.0275	-0.0277	-0.0280	-0.0268	-0.0265	-0.0385
NGC	-0.0310	-0.0270	-0.0228	-0.0363	-0.0363	-0.0364	-0.0305	-0.0260	-0.0287	-0.0257	-0.0306	-0.0391
WOL	-0.0968	-0.1200	-0.0960	-0.1600	-0.1600	-0.1601	-0.1207	-0.0983	-0.1239	-0.1193	-0.0963	-0.1841
OLP	-0.1413	-0.1281	-0.0996	-0.1615	-0.1634	-0.1656	-0.1274	-0.1276	-0.1302	-0.1217	-0.1423	-0.1861
FOR	-0.2481	-0.3178	-0.2461	-0.4434	-0.4411	-0.4452	-0.3237	-0.2548	-0.3141	-0.3182	-0.2482	-0.4393
FSH	-0.2658	-0.3277	-0.2690	-0.4435	-0.4421	-0.4469	-0.3308	-0.2767	-0.3220	-0.3201	-0.2662	-0.4405
COL	-0.2530	-0.3200	-0.2460	-0.4433	-0.4400	-0.4433	-0.3199	-0.2565	-0.3118	-0.3184	-0.2532	-0.4382
OIL	-0.2460	-0.3181	-0.2460	-0.4434	-0.4400	-0.4433	-0.3181	-0.2534	-0.3091	-0.3181	-0.2460	-0.4381
GAS	-0.2460	-0.3176	-0.2460	-0.4433	-0.4421	-0.4433	-0.3190	-0.2535	-0.3091	-0.3183	-0.2460	-0.4386
OMN	-0.2460	-0.3180	-0.2462	-0.4433	-0.4400	-0.4434	-0.3186	-0.2540	-0.3094	-0.3178	-0.2460	-0.4382
PCR	-0.1139	-0.1009	-0.1067	-0.0671	-0.1366	-0.2001	-0.1082	-0.1295	-0.1202	-0.0855	-0.1138	-0.1147
MET	-0.1448	-0.0982	-0.1609	-0.0665	-0.2035	-0.1606	-0.1495	-0.1459	-0.1450	-0.1304	-0.1450	-0.1865
MIL	-0.1513	-0.1372	-0.1544	-0.0358	-0.1403	-0.1605	-0.1465	-0.1386	-0.1613	-0.1195	-0.1513	-0.1385
OFP	-0.2079	-0.1619	-0.2292	-0.2187	-0.3127	-0.3105	-0.2620	-0.2233	-0.2216	-0.2466	-0.2108	-0.2395
B_T	-0.2186	-0.2834	-0.2125	-0.3703	-0.3642	-0.3687	-0.2627	-0.2152	-0.2530	-0.2543	-0.2178	-0.3616
TEX	-0.2387	-0.3119	-0.1933	-0.3473	-0.3331	-0.3318	-0.2530	-0.2208	-0.2587	-0.2511	-0.2350	-0.3738
WAP	-0.2128	-0.3433	-0.2153	-0.3413	-0.3466	-0.3386	-0.2845	-0.2124	-0.2797	-0.2544	-0.2118	-0.3938
LEA	-0.1977	-0.3255	-0.1976	-0.3284	-0.3303	-0.3296	-0.2485	-0.2012	-0.2532	-0.2452	-0.1974	-0.3747
LUM	-0.2519	-0.3278	-0.2501	-0.4502	-0.4553	-0.4523	-0.3261	-0.2581	-0.3144	-0.3262	-0.2516	-0.4432

Table 4.3. *GTAP Own Price Elasticities of Demand*

	CHN	HKG	TWN	ARG	BRA	MEX	LAM	SSA	MNA	EIT	SAS	ROW
PPP	-0.2538	-0.3270	-0.2584	-0.4530	-0.4467	-0.4489	-0.3228	-0.2585	-0.3143	-0.3277	-0.2536	-0.4442
P_C	-0.2501	-0.3331	-0.2576	-0.4813	-0.4679	-0.4452	-0.3324	-0.2615	-0.3198	-0.3386	-0.2503	-0.4478
CRP	-0.2747	-0.3537	-0.2626	-0.4853	-0.4622	-0.4696	-0.3457	-0.2770	-0.3323	-0.3377	-0.2740	-0.4535
NMM	-0.2475	-0.3187	-0.2483	-0.4450	-0.4425	-0.4500	-0.3210	-0.2546	-0.3109	-0.3199	-0.2475	-0.4399
I_S	-0.2460	-0.3177	-0.2460	-0.4433	-0.4401	-0.4434	-0.3182	-0.2534	-0.3095	-0.3199	-0.2460	-0.4394
NFM	-0.2460	-0.3238	-0.2460	-0.4433	-0.4414	-0.4441	-0.3184	-0.2534	-0.3091	-0.3182	-0.2460	-0.4386
FMP	-0.2549	-0.3210	-0.2492	-0.4531	-0.4459	-0.4470	-0.3215	-0.2596	-0.3111	-0.3207	-0.2548	-0.4404
TRN	-0.2042	-0.3166	-0.2373	-0.4677	-0.4606	-0.4500	-0.3080	-0.2188	-0.2800	-0.3143	-0.2039	-0.4250
OME	-0.2637	-0.4195	-0.2274	-0.4535	-0.4648	-0.4519	-0.3142	-0.2486	-0.2848	-0.3110	-0.2584	-0.4236
OMF	-0.2023	-0.3982	-0.2073	-0.4382	-0.4486	-0.4456	-0.2982	-0.2129	-0.2739	-0.2981	-0.2022	-0.4113
EGW	-0.2528	-0.3233	-0.2711	-0.4688	-0.4519	-0.4471	-0.3318	-0.2620	-0.3242	-0.3414	-0.2528	-0.4560
CNS	-0.2460	-0.3176	-0.2460	-0.4434	-0.4400	-0.4434	-0.3192	-0.2535	-0.3101	-0.3204	-0.2460	-0.4386
T_T	-0.3221	-0.4295	-0.4694	-0.5433	-0.5975	-0.7025	-0.5427	-0.3971	-0.5375	-0.5311	-0.3264	-0.6145
OSP	-0.2880	-0.3424	-0.3243	-0.6615	-0.5756	-0.5533	-0.4351	-0.3063	-0.4301	-0.5641	-0.2883	-0.5985
OSG	-0.2856	-0.3185	-0.3053	-0.4439	-0.4408	-0.4743	-0.3454	-0.2798	-0.3580	-0.3781	-0.2863	-0.4840
DWE	-0.2793	-0.3330	-0.3609	-0.4437	-0.5050	-0.4436	-0.3550	-0.2830	-0.3499	-0.3627	-0.2790	-0.4562

not supported by the empirical evidence presented by Rimmer and Powell (1992), who have found that marginal budget shares vary with income. In particular, when those authors examined demand patterns over different levels of economic development, they found that the marginal budget shares of certain goods (e.g., food, beverages and tobacco, and clothing) decline with per capita income, while for other goods (e.g., household furnishings, rent, and fuel), the marginal budget shares increase with per capita income. Under these circumstances, use of the LES of demand would limit an AGE model's ability to depict accurately household behavior in simulations that result in significant household expenditure changes.

For GTAP, we choose the CDE functional form for the expenditure function. The CDE expenditure function was introduced by Hanoch (1978), who discussed models that were more general than the CES but less general than a flexible functional form, for example, the translog.[3] The CDE is based on the assumption of implicit additivity, which, in the case of N commodities, constrains the symmetric $N \times N$ matrix of elasticities of substitution to depend on only N parameters. The CDE also allows for a richer representation of income effects in the demand system. In particular, marginal budget shares may vary with expenditure levels. Calibration of the CDE expenditure function requires data on average budget shares and on income and own-price elasticities of demand for all commodities, as noted above. Calibration procedures are straightforward; however, it is possible that the prespecified information may be inconsistent or may not fit the CDE expenditure function model. In such cases some compromise must be reached. This will be discussed in the section on calibration, below.

Theoretical development of the CDE

In general, an expenditure function can be represented in the following manner:

$$E = G(p,u) = \{\min p'x : f(x) \geq u\}, \tag{4.3}$$

where p and x are N-dimensional vectors of prices and demands, u is utility, and E is minimum expenditure. The function $f(\cdot)$ represents utility, and $G(\cdot)$ is the minimum expenditure function. Function $G(\cdot)$ is homogeneous of degree 1 in prices, allowing the following normalization of prices and expenditure by minimum expenditure:

$$G(E^{-1}p,u) = G(z,u) \equiv 1, \tag{4.4}$$

where the z's are the normalized prices. To obtain the CDE expenditure function, Hanoch (1975) restricts the number of substitution effects to N by imposing additivity in the normalized prices. The implicit function proposed takes the form:

$$G(z,u) = \sum_{i=1}^{N} B_i u^{e_i b_i} z_i^{b_i} \equiv 1, \tag{4.5}$$

where the b_i's are the N parameters, which determine substitution possibilities among commodities in consumption; the e_i's are N expansion parameters, which appear owing to nonhomotheticity in consumption; and the B_i's are scale parameters necessary to specify the function. It is required that $B_i > 0$ and $e_i > 0$, and $b_i < 1$, with either $0 < b_i < 1$ or $b_i < 0$ for all i (Hertel et al. 1991).

If the substitution parameters are rewritten as $\alpha_i = 1 - b_i$, the Allen partial elasticities of substitution can be expressed as:

$$\sigma_{ij} = \alpha_i + \alpha_j - \sum_k s_k \alpha_k - \frac{\delta_{ij}\alpha_i}{s_i}, \tag{4.6}$$

where $\delta_{ii} = 1$, and $\delta_{ij} = 0$ for $i \neq j$, and the s_i's are expenditure shares. The name *constant difference in elasticities* arises due to the fact that the difference between the elasticities of substitution σ_{ij} and σ_{ih} is invariant to index i (Hertel et al. 1994):

$$(\sigma_{ij} - \sigma_{ih}) = (\alpha_j - \alpha_h). \tag{4.7}$$

The expressions for income elasticities of demand are:

$$\eta_i = \left(\sum_k s_k e_k\right)^{-1} \left[e_i(1-\alpha_i) + \sum_k s_k e_k \alpha_k\right] + \left(\alpha_i - \sum_k s_k \alpha_k\right), \tag{4.8}$$

and the expressions for compensated own-price elasticities of demand are:

$$-v_{ij} = -s_i\left[2\alpha_i - \sum_k \alpha_k s_k - \alpha_i / s_i\right]. \tag{4.9}$$

Calibration of the CDE

The income and uncompensated own-price elasticities of private household demand used in GTAP derive from a variety of sources, *none* of which involve econometric estimation using the CDE form. This is a common difficulty when choosing elasticities for AGE models. That is, the functional forms used in the econometric studies from which estimates are drawn do not correspond to the functional forms specified in the model. Furthermore, the sample period used in estimation may not include the benchmark equilibrium year. Finally, econometric studies are based on consumer goods prices, whereas AGE models typically evaluate consumption at producer prices. These divergences cause difficulty, as not all sets of income and own-price elasticities will be representable via the CDE functional form, evaluated at 1992 producer prices.

The problem can be seen clearly for the consumption budget shares and own-price elasticities shown at the top of Table 4.4. These are derived from

Table 4.4. *A 3X3 Example of the CDE*

	USA	EU	ROW
		Consumption Shares	
Foods	0.082048	0.151911	0.212457
Manufactures	0.173766	0.200349	0.198768
Services	0.744186	0.64774	0.588775
	Own-Price Elasticities		
Foods	-0.172441	-0.177254	-0.149364
Manufactures	-0.547482	-0.501926	-0.31344
Services	-0.428958	-0.418842	-0.282822
	α_i Parameters Derived by Solving Equation (4.9)		
Foods	-0.40	-0.23	-0.10
Manufactures	-0.80	0.09	0.20
Services	8.51	3.46	1.60

a three-region, three-commodity aggregation of GTAP (see Chapter 5 for details on aggregation). The α_i parameters derived by solving equation (4.9) for each region are also given in Table 4.4. Plainly, none of these sets of values satisfies the requirement that $0 < \alpha_i < 1$ for all i. Therefore, a procedure must be formulated that, for any set of *target* income and own-price elasticities, determines values of the CDE parameters that yield *model* income and own-price elasticities sufficiently close to the target income and own-price elasticities. This section describes such a calibration procedure for determining CDE parameters.

It is evident from the outset that certain aspects of this calibration procedure, such as the choice of a measure of "closeness," will be, to some extent, arbitrary. Another element of choice is the weight to be given to deviations of own-price elasticities from target values as compared with income elasticities. In the case of the CDE functional form, a "natural" choice in this regard is suggested by equations (4.8) and (4.9), relating elasticities to CDE parameters. The own-price elasticities are determined by the α_i parameters, while the income elasticities depend on both α_i and e_i parameters. Thus the procedure adopted was to determine α_i's to ensure closeness of the own-price elasticities implied by equation (4.9) with target elasticities, and to use these α_i's in equation (4.8) when determining an appropriate set of e_i parameters.

The calibration procedure for CDE parameters entails solving two constrained minimization problems. The first determines the CDE α_i parameters by seeking a good fit to the target own-price elasticities. The second, taking the α_i values from the first as given, determines the e_i parameters by seeking a good fit to the target income elasticities. The constraints imposed are of two types. First are those on CDE parameters required for the regularity of the CDE form. Second is the requirement that income elasticities are greater than (less than) or equal to 1 if the corresponding targets are greater than (less than) 1. This latter constraint ensures that goods that were superior (inferior) as represented by the target elasticities remain so after calibration.

The constrained minimization problem for determining the CDE α_i parameters can be represented formally as: given ν_{ii}^{target}, choose ν_{ii}, and α_i to minimize:

$$\sum_i \nu_{ii}[\log_e(\nu_{ii}/\nu_{ii}^{target}) - 1] \tag{4.10}$$

subject to $0.01 \leq \alpha_i \leq 0.99$, and equation (4.9), where ν_{ii}^{target} = target-compensated own-price elasticities; ν_{ii} = compensated own-price elasticities arising from calibration; α_i = CDE substitution parameters arising from calibration.

The regularity requirement that $0 < \alpha_i < 1$ has been replaced by the inequality constraint shown. Otherwise the problem may not have a solution if the objective function attained its minimum on the boundary of the region $\{\alpha_i\colon 0 < \alpha_i < 1 \text{ for all } i\}$. The objective function is strictly convex, and the feasible region convex, so a unique minimum exists.

The constrained minimization for determining the CDE e_i parameters can be represented formally as: given η_i^{target}, choose η_i, and e_i to minimize:

$$\sum_i s_i(\eta_i - \eta_i^{target})^2 \tag{4.11}$$

subject to equation (4.8),

$$0.01 \leq e_i, \sum_i s_i\eta_i = 1, \textit{ and } (\eta_i - 1) * (\eta_i^{target} - 1) \geq 0,$$

where η_i^{target} = target income elasticities; η_i = income elasticities resulting from calibration; and e_i = CDE expansion parameters resulting from calibration.

The regularity requirement that $e_i > 0$ has been replaced by the inequality constraint shown, for the same reason that the regularity condition on the α_i was altered in the first minimization. It should be noted that the second constraint ensures that the income elasticities derived as the solution to this minimization will satisfy the Engel condition. The third constraint ensures that the calibrated income elasticities lie on the same side of one as the target elasticities.

Although many software packages exist in which these constrained minimizations could be formulated and solved with ease, they have been implemented in GEMPACK. This has been done to ensure that GTAP users do not require access to any other software in order to perform the entire range of operations, from data aggregation to printing of simulation results.

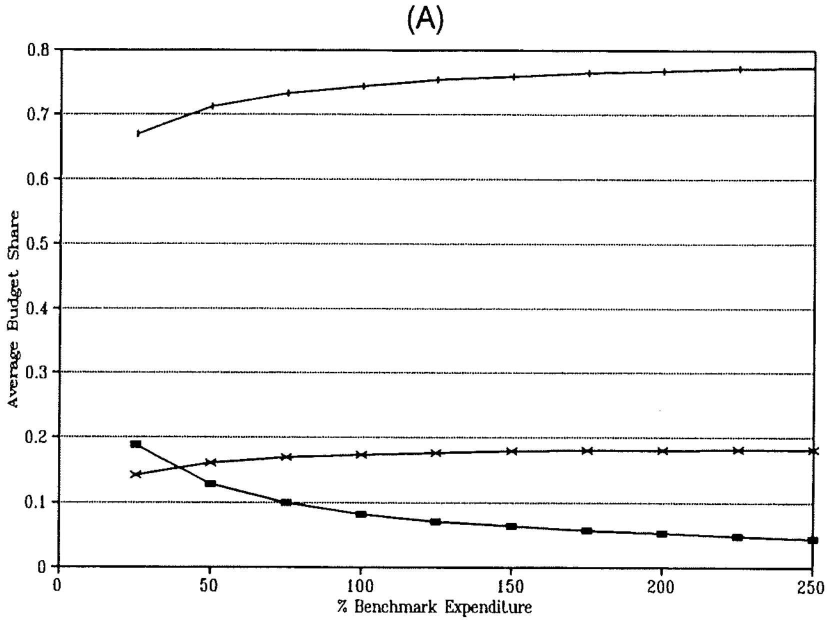


Figure 4.1 *(above and opposite)*. Behavior of average budget shares as expenditure increases in *USA*: (A) average; (B) marginal.

Performance of the CDE implicit expenditure function

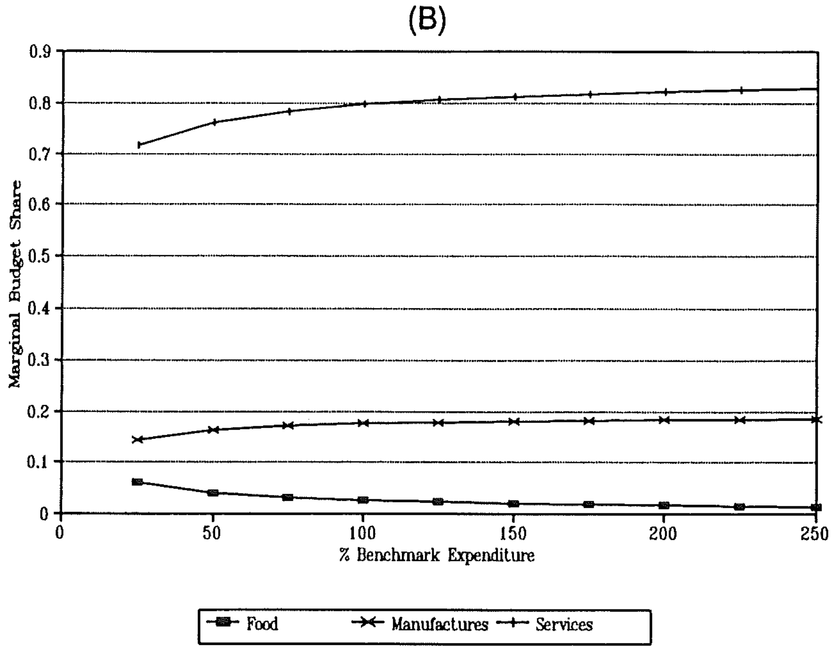
We now examine the behavior of the average and marginal budget shares, and income elasticities of demand, as the level of expenditure in each region varies from the benchmarklevels. Using the calibrated parameters for the 3x3 model (including the scale parameters (B_i's)) and equation (4.5), utility levels are computed using a range of 25–250% of the benchmark level of expenditure for each region. Once per capita utility has been calculated, demands for each good in each region are computed using the following equation:

$$x_i = \frac{B_i b_i u^{b_i e_i} z_i^{b_i - 1}}{\sum_{k=1}^{N} B_k b_k u^{b_k e_k} z_k^{b_k}} \quad i = 1 \ldots N. \tag{4.12}$$

Average budget shares are computed by using the following formula:

$$s_i = \frac{p_i x_i}{\sum_{k=1}^{3} p_k x_k}. \tag{4.13}$$

The income elasticities are computed using equation (4.8). Finally, the marginal budget shares are computed using:



$$\theta_i = s_i \eta_i. \tag{4.14}$$

Figure 4.1 shows plots of the average (panel *a*) and marginal (panel *b*) budget shares for the US; Figures 4.2*a* and *b* and 4.3*a* and *b* display average and marginal budget shares for the EU and the rest of the world (ROW), respectively. As total expenditure increases, the average budget shares for services and manufactured goods increase in all three regions. As the economies grow, the demand for these goods grows. The average budget shares for food decline as the level of expenditure increases in all regions. This decline is greatest for food in the US.

Notice that as expenditure increases, the marginal budget shares for services and manufactures grow in all regions, but both are quite flat for the US. In the EU and ROW the marginal shares for services also change relatively little as incomes grow. The marginal budget shares for food decline gradually for all three regions. This behavior agrees with the results of Rimmer and Powell (1992) for food in Australia. As the economy grows, households spend a smaller proportion of marginal increases in income on food.

Figure 4.4*a–c* shows the behavior of the income elasticities as expenditure increases in each region. These elasticities decline in all regions for all three goods as income increases. This result coincides with prior beliefs about the income responsiveness of demand as wealth increases. In sum, the CDE

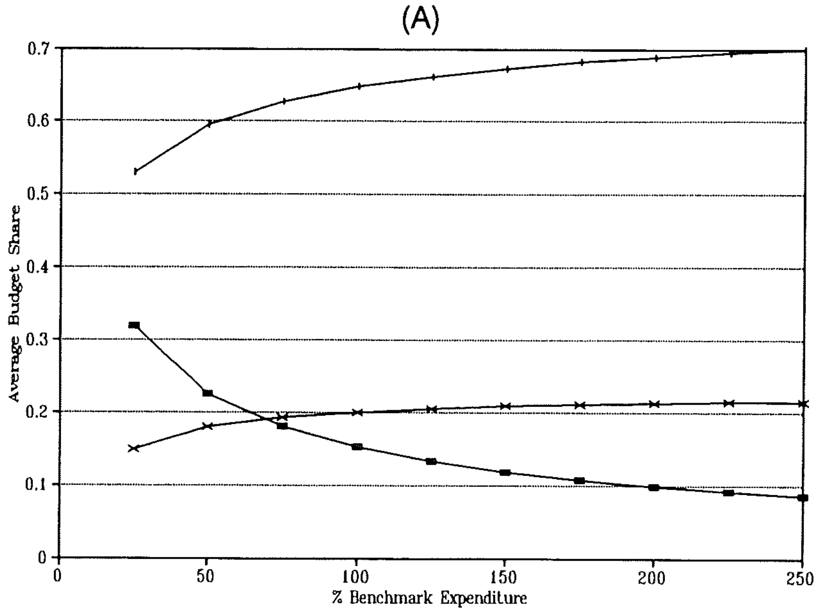


Figure 4.2 (*above and opposite*). Behavior of average budget shares as expenditure increases in *EU*: (A) average; (B) marginal.

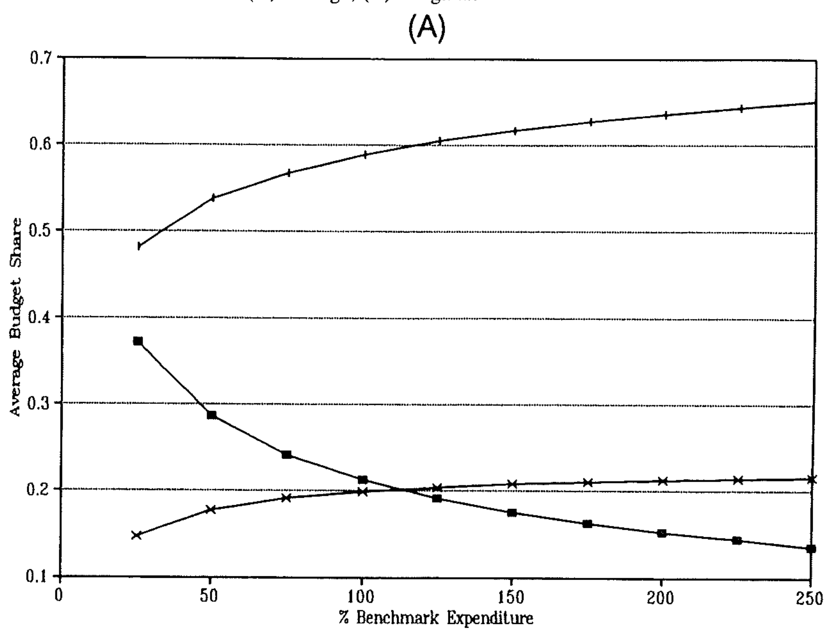
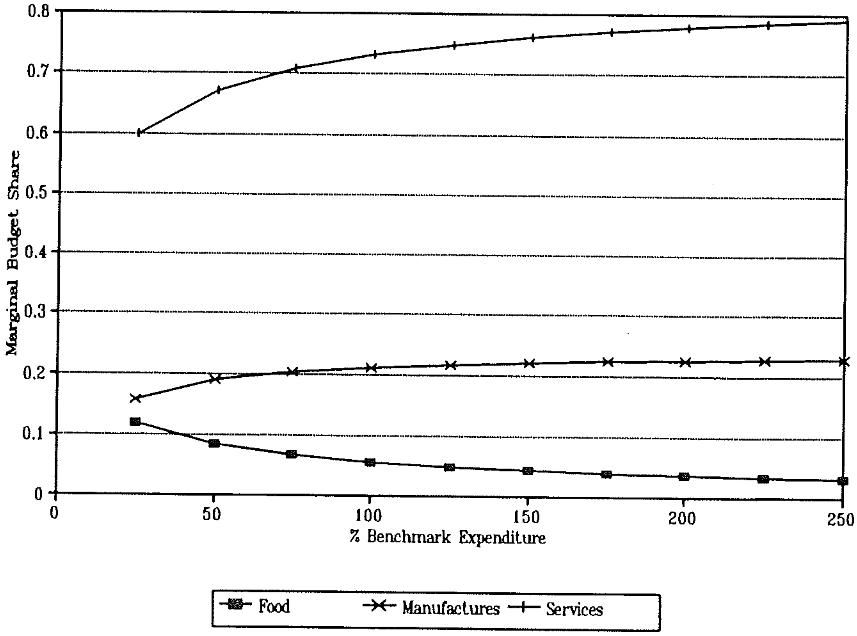
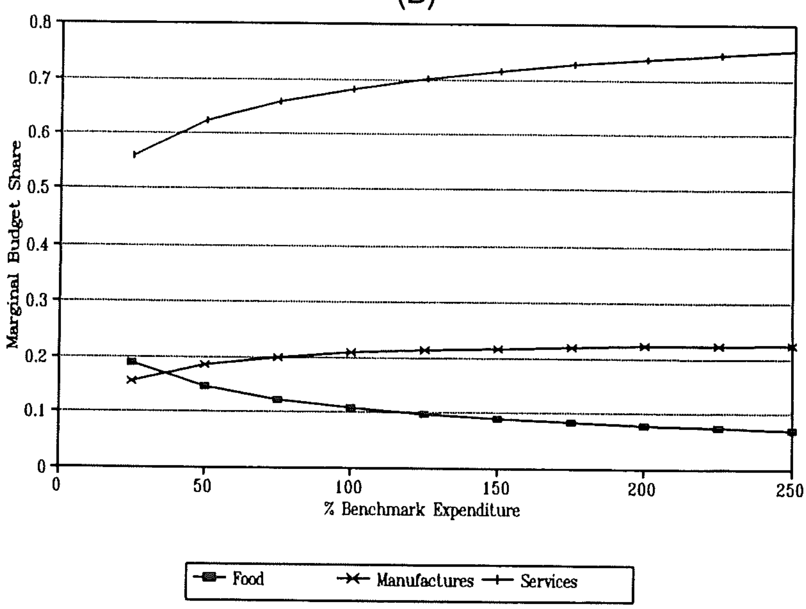


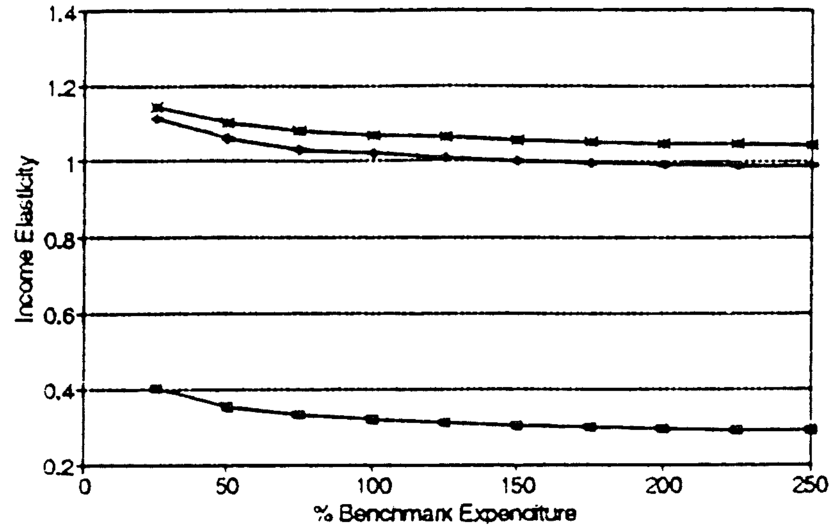
Figure 4.3 (*above and opposite*). Behavior of budget shares as expenditure increases in *ROW*: (A) average; (B) marginal.

(B)


Marginal Budget Share
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
250
% Benchmark Expenditure
Food
Manufactures
Services

(B)


Marginal Budget Share
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
250
% Benchmark Expenditure
Food
Manufactures
Services



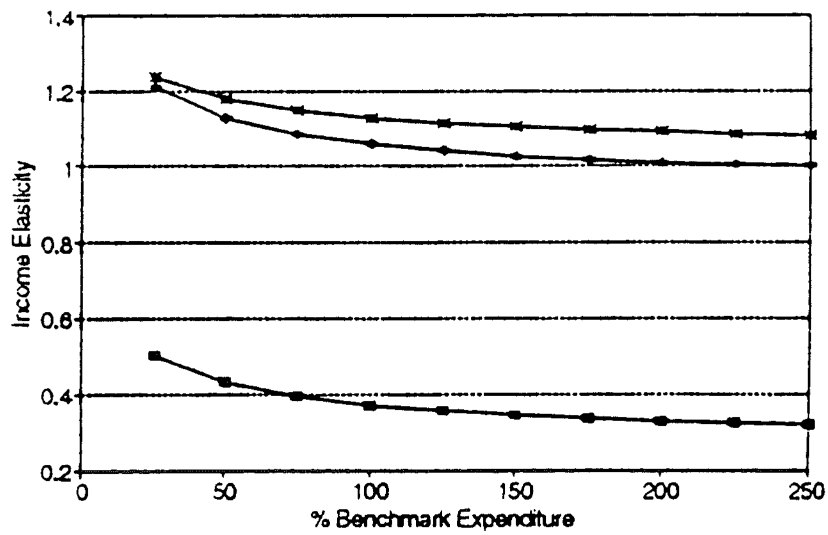
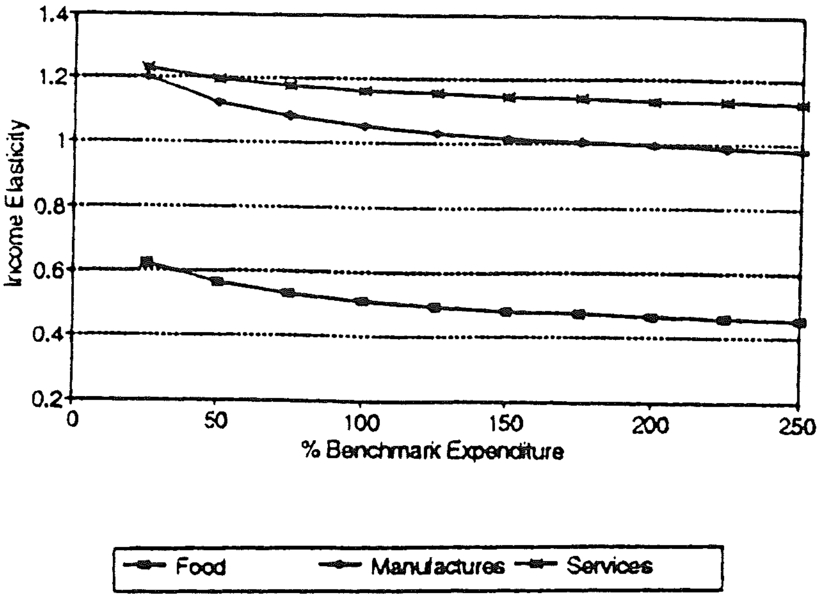


Figure 4.4 (*above and opposite*). Behavior of income elasticities as expenditure increases: (top) *USA*; (bottom) *EU*; (opposite) *ROW*.



expenditure function appears to behave satisfactorily under a growth scenario. As such, it appears to be a good choice for modeling household preferences.

NOTES

1. By *average household budget shares*, we mean $p_i x_i / E$, where p_i and x_i are the price and quantity demanded, respectively, for commodity i, and E is total expenditure.
2. By *marginal budget shares*, we mean $p_i \partial x_i / \partial E$.
3. The term *flexible functional form* is usually used for those forms that provide a second-order approximation at a point to the true function (Fuss, McFadden, and Mundlak 1978).

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CHAPTER 5

Aggregation and computation of equilibrium elasticities

Thomas W. Hertel, D. Kent Lanclos, Kenneth R. Pearson, and Padma V. Swaminathan

I Introduction and overview

The Global Trade Analysis Project (GTAP) benchmark data and parameters are specified for 37 commodities and 24 regions. Due to the size of this data set, an aggregated version of the data base and parameters will be desired for most GTAP simulations. The precise dimensions of each aggregation will depend on the problem at hand. Experienced users tend to favor strategic aggregations that allow them to focus on key sectors and regions of interest. This makes the job of sorting through the simulation results less daunting. For teaching purposes, we usually begin with the three-region, three-commodity (3x3) aggregation referred to in Chapters 2 and 4. Section II introduces you to the GTAP aggregation facility that created this 3x3 data set. We will also examine some of the key value flows, as well as the full parameter file. In section III, local behavior of the 3x3 model will be examined through the use of general equilibrium demand elasticities. This offers a valuable summary of the interaction between theory, data, and parameters in the model.

II Aggregation of the GTAP data

The user specifies the desired aggregation of the GTAP data base by filling in a *template* file.[1] This involves defining names for the aggregated commodities and associating them with disaggregate GTAP commodity categories, then doing the same for regions. Figure 5.1 presents the aggregation template file for the 3x3 aggregation used in this chapter. In part 1 of this file, we define the three aggregated tradeable commodities, which are denoted as *food* (food and agriculture), *mnfcs* (resources and manufacturing), and *svces* (services). In Part 2, these are linked with the 37 individual commodities in the GTAP data base. Parts 3 and 4 of the template file accomplish the same thing for regions. In this case, *USA* and European Union (*EU*) are left

```
! 1. AGGREGATED COMMODITIES
!   In this section, the user fills in:
!        a) short names
!        b) (optional) explanatory text
!  NAME          | Explanatory Text
!                | (Rest of line)
= = = = = = = = = = = = = = = = = = = = =
food            & food and agriculture
mnfcs           & resources and manufactures
svces           & all services
= = = = = = = = = = = = = = = = = = = = = = = = =
! 2. COMMODITY AGGREGATION MAPPING
!  In this section the user fills in the short name of
!  the appropriate aggregated commodity (from the previous
!  list) for each GTAP commodity.
!
!     GTAP COMMODITY   |  Aggregated Commodity
= = = = = = = = = = = = = = = = = = = = = = = = = = = = = = =
pdr, paddy rice                          & food
wht, wheat                               & food
gro, grains                              & food
ngc, nongrain crops                      & food
wol, wool                                & food
olp, other livestock                     & food
for, forestry                            & mnfcs
fsh, fisheries                           & mnfcs
col, coal                                & mnfcs
oil, oil                                 & mnfcs
gas, gas                                 & mnfcs
omn, other minerals                      & mnfcs
pcr, processed rice                      & food
met, meat products                       & food
mil, milk products                       & food
ofp, other food products                 & food
b_t, beverages and tobacco               & food
tex, textiles                            & mnfcs
wap, wearing apparel                     & mnfcs
lea, leather etc.                        & mnfcs
lum, lumber                              & mnfcs
ppp, pulp, paper, etc.                   & mnfcs
p_c, petroleum and coal                  & mnfcs
crp, chemicals, rubbers, and plastics    & mnfcs
nmm, nonmetallic minerals                & mnfcs
i_s, primary ferrous metals              & mnfcs
nfm, nonferrous metals                   & mnfcs
fmp, fabricated metal products           & mnfcs
trn, transport industries                & mnfcs
ome, machinery and equipment             & mnfcs
omf, other manufacturing                 & mnfcs
egw, electricity, water, and gas         & svces
cns, construction                        & svces
t_t, trade and transport                 & svces
osp, other services (private)            & svces
osg, other services (govt)               & svces
dwe, ownership of dwellings              & svces
= = = = = = = = = = = = = = = = = = = = = = = = =
```

Figure 5.1. Template file for the 3x3 aggregation.

```
!
! 3. AGGREGATED REGIONS
!  In this section, the user fills in:
!
!       a) NAMES
!       b) (optional) explanatory text
!
!                | Explanatory Text
! NAME           | (Rest of line)
= = = = = = = = = = = = = = = = = = = = = = =
 USA          & United States of America
 EU           & European Union
 ROW  &  Rest of the World
= = = = = = = = = = = = = = = = = = = = = = = =
!
! 4. REGIONAL AGGREGATION MAPPING
!
! In this section, the user fills in the short
! name for the aggregated region to which each
! of the GTAP regions belongs.
!
!    GTAP REGION  |  Aggregated Region
= = = = = = = = = = = = = = = = = = = = = = = = = = =
AUS  Australia                          & ROW
NZL  New Zealand                        & ROW
CAN  Canada                             & ROW
USA  United States of America           & USA
JPN  Japan                              & ROW
KOR  Republic of Korea                  & ROW
EU   European Union                     & EU
IDN  Indonesia                          & ROW
MYS  Malaysia                           & ROW
PHL  Philippines                        & ROW
SGP  Singapore                          & ROW
THA  Thailand                           & ROW
CHN  China                              & ROW
HKG  Hong Kong                          & ROW
TWN  Taiwan                             & ROW
ARG  Argentina                          & ROW
BRA  Brazil                             & ROW
MEX  Mexico                             & ROW
LAM  Rest of Latin America              & ROW
SSA  Sub Saharan Africa                 & ROW
MNA  Middle East and North Africa       & ROW
EIT  Economies In Transition            & ROW
SAS  South Asia                         & ROW
ROW  Rest of World                      & ROW
```

Figure 5.1. (*Continued*) Template file for the 3x3 aggregation.

disaggregated, while all other regions are lumped together in the rest of the world (*ROW*). Since this file is the definitive statement of what is in each composite category, it is always provided with any aggregation of the data base.

Aggregation of value flows

Aggregation of value flows in the benchmark data involves the simple summation of appropriate component elements. For example, disaggregate consumer expenditures for agricultural and processed food products are summed to obtain total consumer expenditures for the aggregate category, food. Similarly, when aggregating regions, consumer expenditures for each commodity are summed across disaggregate regions. For variables that are source-specific (e.g., trade flows), the regional aggregation also aggregates across these sources.

Even the 3x3 aggregation results in a sizeable data set. Tables 5.2 and 5.3 present *portions* of this data base. In Table 5.1, the disposition of domestic output in the US is presented. At the top of the table the value of output at domestic market prices is presented for each of the aggregate traded commodities. The next three lines break out domestic and export sales, as well as sales to the global transport sector. Since the latter entry (VST) comprises only trade and transport services, it is equal to zero for food and manufactures. Part II of this table reports the breakdown of exports across destinations. Note that there is no intraregional trade for an individual country such as *USA*.

Part III of Table 5.1 decomposes domestic sales into those destined for private and government households and intermediate inputs. The bulk of manufactured goods are sold to other firms, while sales to households constitute a majority of the food and services output in the US. Intermediate sales are broken out at the bottom of Table 5.4. At this level of aggregation, own-use of inputs is very important. Indeed, the bulk of farm and food intermediate sales takes place within the food sector, as defined by the aggregation template in Figure 5.1. This is followed by sales to the services sector. The manufacturing and services sectors are important purchasers of one another's outputs. These sectors also supply virtually all the inputs to the capital goods (investment) sector.

Table 5.2 shows the sources and uses of imports, at domestic market prices, in the *USA* region. At the top of this table, imports sourced from the three regions of origin are reported. Again, the absence of intraregional trade at the national level is noted. The bulk of US imports is shown to be sourced from the composite, ROW region. The sum of imports from all sources, VIM, is reported in the next line of Table 5.2. Note that manufacturing imports exceed imports of food or services by an order of magnitude. This line is followed by the disposition of imports across households and intermediates uses within the *USA* region. The majority of trade is shown to take place in intermediate goods. Finally, the breakdown of imports for intermediate use by individual sector is shown in part II of Table 5.2.

Aggregation of parameters

Aggregation of behavioral parameters of the model is more involved than aggregation of value flows. The relevant behavioral parameters are the uncompensated own-price and income elasticities of demand, the elasticities of

Table 5.1. ***Disposition of Domestic Output in the US: 3x3 Aggregation***

	i = food	i = mnfcs	i = svces
I. Domestic Output			
$VOM(i,USA)$[a]	**663,932**[b]	**2,856,656**	**6,548,007**
$= VDM(i,USA)$	615,418	2,480,245	6,395,376
$+ \sum_{s\in REG} VXMD(i,USA,s)$	48,514	376,411	135,049
$+ VST(i,USA)$	0	0	17,582
II. Exports			
$\sum_{s\in REG} VXMD(i,USA,s)$	**48,514**	**376,411**	**135,049**
$= VXMD(i,USA,USA)$	0	0	0
$+ VXMD(i,USA,EU)$	8,564	92,695	51,672
$+ VXMD(i,USA,ROW)$	39,950	283,716	83,377
III. Domestic purchases			
$VDM(i,USA)$	**615,418**	**2,480,245**	**6,395,376**
$= VDPM(i,USA)$	318,045	525,012	2,998,010
$+ VDGM(i,USA)$	10,993	191,368	870,490
$+ \sum_{j\in PROD\_COMM} VDFM(i,j,USA)$	286,380	1,763,865	2,536,876
IV. Intermediate, domestic purchases			
$\sum_{j\in PROD\_COMM} VDFM(i,j,USA)$	**286,380**	**1,763,865**	**2,536,876**
$= VDFM(i,food,USA)$	205,558	84,772	146,429
$+ VDFM(i,mnfcs,USA)$	6,410	817,396	570,221
$+ VDFM(i,svces,USA)$	74,399	624,365	1,362,530
$+ VDFM(i,cgds,USA)$	13	237,332	457,696

a Aggregate values in boldface.
b All units in 1992 $US million.

substitution in value-added, and the elasticities of substitution among foreign goods and between domestic and foreign goods. The own-price and income elasticities of demand vary by commodity and region, whereas the substitution elasticities vary only by commodity. Rather than simply computing arithmetic means of the disaggregate parameters, we compute their expenditure share-weighted means.

In the case of consumer demand elasticities, we proceed as follows:

1. We ensure that the Engel aggregation condition holds for the disaggregate data and parameters by proportionally adjusting all income elasticities as required.

Table 5.2. ***Sources and Uses of Imports in the US: 3x3 Aggregation***

	i = food	i = mnfcs	i = svces
I. Sources and Uses of Imports			
$VIMS(i, USA, USA)$	0	0	0
+ $VIMS(i, E\_U, USA)$	6,859	97,204	15,146
+ $VIMS(i, ROW, USA)$	26,046	472,786	54,940
$\mathbf{VIM(i, USA)}$	**32,905**	**569,990**	**70,086**
= $VIPM(i, USA)$	14,563	179,406	28,790
+ $VIGM(i, USA)$	429	31,457	3,530
+ $\sum_{j \in PROD\_COMM} VIFM(i, j, USA)$	17,912	359,127	37,766
II. Uses of Intermediate Imports			
$\sum_{j \in PROD\_COMM} \mathbf{VIFM(i, j, USA)}$	**17,912**	**359,127**	**37,766**
= $VIFM(i, food, USA)$	13,631	8,208	1,002
+ $VIFM(i, mnfcs, USA)$	373	207,796	12,859
+ $VIFM(i, svces, USA)$	3,906	63,590	18,537
+ $VIFM(i, cgds, USA)$	1	79,531	5,366

a Aggregate values in boldface.
b All units in 1992 $US million.

2. We apply the Slutsky condition to derive *compensated* own-price elasticities based on the GTAP data for *uncompensated* own-price elasticities and the income elasticities from the previous step.
3. We obtain expenditure share-weighted means of the disaggregate income and *compensated* own-price elasticities for the aggregation in question.
4. We again make sure that the Engel aggregation condition holds for the aggregated data and income elasticities by proportionally adjusting all income elasticities. The underlying parameters of the CDE expenditure function are calibrated to the income and compensated own-price elasticities from items 3 and 4.

Since the elasticities of substitution are not region-specific, only aggregation across commodities is necessary. Hence, the share weights used in commodity aggregation are global values. For the elasticities of substitution in value-added, sectoral payments to land, labor, and capital are summed to obtain total value-added by sector, which is the weight used in the aggregation. For the elasticities of substitution among foreign goods and between domestic and foreign goods, total expenditures for imports and total expenditures for

Table 5.3. ***Equilibrium Price Elasticities of Demand: 3X3 Aggregation***

qo\pm	usa_f	usa_m	usa_s	eu_f	eu_m	eu_s	row_f	row_m	row_s
				A. Full GE Closure					
usa_f	-0.663	1.074	0.225	0.112	-0.196	-0.041	0.369	-0.600	-0.162
usa_m	0.071	-1.990	0.662	-0.017	0.209	-0.086	-0.060	0.434	-0.277
usa_s	0.014	0.526	-0.205	-0.001	-0.051	0.027	-0.002	-0.095	0.090
eu_f	0.098	-0.209	-0.015	-0.625	0.727	0.420	0.317	-0.503	-0.151
eu_m	-0.019	0.224	-0.065	0.080	-1.405	0.624	-0.071	0.477	-0.294
eu_s	-0.005	-0.052	0.024	0.045	0.393	-0.261	-0.013	-0.104	0.117
row_f	0.126	-0.271	-0.018	0.110	-0.211	-0.031	-0.415	0.290	0.528
row_m	-0.030	0.295	-0.080	-0.038	0.304	-0.109	0.057	-0.689	0.512
row_s	-0.009	-0.081	0.037	-0.002	-0.095	0.052	0.046	0.246	-0.309
to(i,r)	-0.760	-2.593	-1.467	-0.734	-1.848	-1.571	-0.748	-1.371	-2.004
				B. PE Closure with Endowment Prices and Regional Incomes Fixed					
usa_f	-0.701	-0.255	-0.462	0.107	0.027	0.018	0.391	0.031	0.053
usa_m	-0.085	-1.809	-0.834	0.007	0.339	0.065	0.029	0.915	0.220
usa_s	-0.080	-0.340	-0.959	0.002	0.031	0.026	0.009	0.078	0.069
eu-f	0.097	0.035	0.039	-0.696	-0.272	-0.306	0.341	0.048	0.052
eu_m	0.007	0.284	0.073	-0.140	-1.690	-0.665	0.017	0.886	0.172
eu_s	0.001	0.020	0.024	-0.103	-0.299	-0.901	-0.001	0.031	0.040
row_f	0.139	0.044	0.051	0.119	0.026	0.015	-0.527	-0.334	-0.334
row_m	-0.002	0.406	0.097	-0.000	0.471	0.051	-0.176	-1.325	-0.734
row_s	-0.000	0.045	0.042	-0.001	0.038	0.026	-0.140	-0.427	-0.861
to(i,r)	-0.688	-0.676	-0.745	-0.663	-0.620	-0.812	-0.653	-0.572	-0.729

imported and domestic commodities are calculated. As above, share weights are then calculated for the disaggregate members of each aggregate commodity and used to weight the disaggregate substitution elasticities prior to summation.

Figure 5.2 reports the parameter file used in the 3x3 aggregation. It begins with the calibrated CDE parameters, SUBPAR and INCPAR, which are

```
! The matrix SUBPAR(%1,%2) with %1 in IND, %2 in REG.
!%2= USA        EU          ROW
 0.866678       0.897081    0.967472       !%1=food
 0.239291       0.317116    0.669294       !%1=mnfcs
 9.999990E-03      9.999990E-03   9.999990E-03   !%1=svces

! The matrix INCPAR(%1,%2) with %1 in IND, %2 in REG.
!%2= USA        EU          ROW
 0.133962       0.160812    0.331707       !%1=food
 0.793119       0.789978    0.838876       !%1=mnfcs
 1.14379        1.26177     1.29555        !%1=svces

! Values of ESUBD(IND) - an array of size 3
!--------------------
!  food          mnfcs              svces
   2.39901       2.79556            1.94365

! Values of ESUBM(IND) - an array of size 3
!--------------------
!
!  food          mnfcs              svces
   4.63905       6.08810            3.91673
!
! Values of ESUBVA(IND) - an array of size 4
!---------------------
!
!  food          mnfcs              svces
   0.789314      1.21992            1.38946
!  CGDS
   0.000000
!
! Values of ETRAE  (a single number)
!---------------
!
  -1.00000
!
! Values of RORFLEX(REG) - an array of size 3
!----------------------
!
!  USA         EU              ROW
   10.0000     10.0000         10.0000
!
! Values of RORDELTA  (a single number)
!------------------
!
   0.000000
```

Figure 5.2. Parameters for the 3x3 aggregation.

commodity- and region-specific. These are followed by the region-generic elasticities of substitution between domestic goods and imports (ESUBD), between imports from different sources (ESUBM), and among the components of value-added (ESUBVA). The next entry, ETRAE, specifies the elasticity of transformation between alternative uses of the sluggish endowment commodities – in this case, farmland. The final sets of parameters are relevant to the interregional allocation of investment. RORFLEX, the flexibility of investment allocation, is permitted to vary by region. It is operational only when RORDELTA is equal to 1. In this parameter file *RORDELTA* = 0, so that the global banking sector's regional investment portfolio is fixed.

III Equilibrium elasticities

Price and income elasticities are the driving mechanisms behind agents' demand (and supply) responses to changes in market prices. The new postshock equilibrium reached by the model critically depends on these elasticities. Elasticities are, by definition, partial equilibrium phenomena. Therefore, the meaning of elasticities in a general equilibrium (GE) framework requires further discussion. For example, it will be seen that the choice of closure influences not only the magnitude but also the sign of the elasticities. In this section we examine two closures: (1) the standard GE closure and (2) a partial equilibrium closure in which we abstract from income effects and supply-side interactions.

The matrix of price elasticities of demand, $[\varepsilon_{(i,r),(j,s)}]$, is generated for all traded commodities in all regions, ($i,j \in$ *TRAD_COMM*, $r,s \in$ *REG*), by shocking $to(i,r)$ by enough to raise the market price, $pm(i,r)$, by 1%, one commodity and one region at a time. We then record the effect on output $qo(i,r)$. The own-price elasticity of demand is simply the ratio $qo(i,r)/pm(i,r)$. The own- and cross-price elasticities form a square matrix whose dimension is the product of *#TRAD_COMM* and *#REG*. The matrix of price elasticities for two important closures will be discussed below. The task of computing these elasticities for a disaggregated model, say, with five regions and six traded commodities, can become very cumbersome and time-consuming even for a single choice of closure. However, the reader will be relieved to know that this has been automated via a series of GEMPACK programs that can produce these matrices in one stroke.[2]

Standard closure

In the standard (GE) closure of the GTAP model, prices, quantities of all nonendowment commodities, and regional incomes are endogenous variables. Conversely, policy variables, technical change variables, and population are exogenous to the model. By virtue of Walras' Law, we omit the equation forcing global savings to equal investment. Their equality may be checked after the fact by examining the value of *walraslack*. If this is zero, then the solution is consistent in a general equilibrium sense. The price elasticities that result from this GE closure are true *general equilibrium* demand elasticities, reflecting adjustment in all markets. These elasticities for the 3x3 aggregation are presented in part A of Table 5.3.[3] Each column may be generated by shocking the associated power of the output tax by the amount indicated in the last row of this table. For example, *to("usa", "food") = –.760* will cause the market price of food produced in the *US* region to rise by 1%, and the demand (and hence supply) to fall by 0.663%, as noted by the first diagonal entry.

The diagonal elements in part A of Table 5.3 represent the GE, own-price elasticities of demand, $\varepsilon_{(i,r),(i,r)}$, and are negative. They are largest for the heavily traded manufacturing products, and smallest for the dominant, lightly traded service sector. The blocks of submatrices along the diagonal contain the intraregional cross-price elasticities of demand, $\varepsilon_{(i,r),(j,r)}, i \neq j$. These entries are positive, indicating GE substitutability. The off-diagonal blocks of submatrices show interregional cross-price elasticities of demand, $\varepsilon_{(i,r),(j,s)}, r \neq s$, and are of mixed sign. Furthermore, the matrix is qualitatively symmetric.

The importance of the elasticities reported in Table 5.3 cannot be overemphasized. For example, the GE own-price elasticity of demand for a given product is critical for determining the distribution of benefits from technical change in an industry (see Chapter 13). These own-price elasticities depend on a number of factors including: the mix of final demands, private households' own-price elasticity of demand, and exposure to trade.

Cross-price elasticities determine the nature of the relationship between a pair of commodities. In this 3x3 aggregation, with the standard GE closure, we observe block substitutability along the diagonal such that $\varepsilon_{(i,r),(j,r)} > 0$ for $i \neq j$. This is due to the interplay of *both* demand and supply considerations. In particular, an increase in $pm(i,r)$ causes a contraction in the demand for commodity i in region r as agents substitute away from the higher-priced commodity. At this point, GE supply-side forces come into play, since the resources released from sector i in r must be absorbed by other sectors. Therefore, outputs of all sectors $j \neq i$ in region r increase. This increase in other sectors' outputs underscores the key role of intersectoral competition for mobile resources in determining the sectoral responses to any shock to the economy.

The blocks of off-diagonal submatrices measure the responses *across* regions for both own- and cross-commodities. Many, although not all, of the strongest cross-region linkages exist for similar commodities, $\varepsilon_{(i,r)(i,s)}, r \neq s$. These elasticities are positive, indicating substitutability. This is to be expected, given the strong substitutability between imports and domestic goods (σ_D = ESUBD) shown in Figure 5.2. Meanwhile, the interregional cross-price elasticity between dissimilar products, $\varepsilon_{(i,r)(j,s)}, i \neq j, r \neq s$, exhibits *complementarity*, although the magnitude of this response is generally smaller. This derives from the supply-side interactions again. With $qo(i,s) > 0$ in response to $pm(i,r) > 0$, resources are drawn away from other sectors in region s. Therefore, $qo(j,s) < 0$ for $j \neq i$ in $s \neq r$.

To summarize, let us consider what happens when the price of manufactures supplied by the *USA* region increases by 1% owing to an output tax on that sector. This may be ascertained by looking down the second column in part A of Table 5.3. The first point to note is that the demand for *USA* manufacturing output falls by almost 2%. This releases resources to the other two sectors, which *expand* as a result. This expansion is especially strong in the food sector, where output increases by 1.07%. This strong response is a result of the sector's relatively small claim on economywide resources, and its significant export opportunities. (Note the large share of *USA* food exports in output in Table 5.1.) The proportionate response of services is only half as large, for precisely the opposite reasons (large sector with little trade).

The impact of the *USA* manufactures price hike on the other two regions is also significant, with the *EU* and *ROW* regions' manufacturing output increasing by .22% and .29%, respectively. This serves to draw resources *away from* the food and services sectors in these other regions. When these supply-side forces are combined with reduced prices for the competing *USA* food and services outputs, due to an expansion in those sectors, there is a significant reduction in food and services outputs outside the *USA*. This multiregion, GE linkage is particularly striking in the case of *ROW* food production, where the 1% increase in *USA manufacturing* price has resulted in a *.27% reduction* in *ROW food* production.

All the results discussed above are dependent on the GE closure that we have used. These are properly viewed as *unconditional* elasticities, since all endogenous variables are permitted to adjust to their new equilibrium values, following the price shock. However, it is also useful to examine various *conditional* elasticities to obtain insight into individual components of the full model. In the next closure we abstract from supply-side effects by fixing endowment prices. Also, regional income (and hence expenditure) is fixed. This permits us to focus on the substitution relationships deriving from the demand side of the model.

Partial equilibrium (PE) closure with endowment prices and regional incomes fixed

By exogenizing regional incomes, we can focus on the uncompensated price elasticities of final demand. It also allows us to generate income elasticities of demand. This is accomplished by endogenizing *incomeslack(r)* and exogenizing *y(r)*. Endowment prices are fixed by swapping *pm(i,r)* $i \in$ *ENDW_COMM*, with *endwslack(i,r)*. This allows us to isolate pure expansionary (contractionary) effects in the supply of TRAD_COMM. Producers have no incentive to substitute among primary factors in their value-added nests because primary factor prices do not change. The fixed-coefficients nature of the model at the topmost level in the utility/production trees means the expansionary (contractionary) effect in the value-added nest is matched in sign and magnitude by all the intermediate input nests. The only firm side substitution will occur in the Armington nests (ESUBD and ESUBM). Finally, note that since we have destroyed the GE consistency of the model, we can no longer expect Walras' Law to hold. Therefore, *walraslack* is exogenized and *psave* (formerly the numeraire) is endogenized.

The conditional PE price elasticities are shown in part B of Table 5.3. In contrast to the earlier matrix, this one is not fully symmetric in a qualitative sense. Also, now the blocks of submatrices along the diagonal show net complementarity, $\varepsilon_{(i,r),(j,r)} < 0,\ i \neq j$. This is the relationship opposite from that identified among commodities within a region under the GE closure. The difference is entirely due to the absence of supply-side competition for resources. [With *endwslack(i,r)* endogenous, the factor market clearing conditions are no longer applicable.] Therefore, the only remaining linkage is through the demand side. Here, one might expect the increase in the manufactures price, for example, to stimulate the demand for food and services, thereby *increasing* their outputs (i.e., intraregional substitution). However, this effect is dominated by the role of manufactures as an intermediate input in the other sectors. Higher prices for this input raise the price of food and manufacturing products, thereby reducing demand. This is the dominant effect for all intraregional commodity relationships. Regarding *interregional* commodity relationships in the model, we see that substitution is the dominant response.

Income elasticities of demand are obtained, using this same PE closure, by perturbing regional incomes by 1%, one region at a time. These are reported in Table 5.4. They measure the percentage change in demand for output of commodity i in region r, $qo(i,r)$, when income in region s, $j(s)$, rises by 1%. Unlike the private household income elasticities of demand presented in Chapter 4, the elasticities do not satisfy Engel aggregation on a regional basis. To see this, one simply has to note that *all* income elasticities of demand in this table are less than 1. This is due to the presence of *leakages*. For example, some of the income in the EU region is spent on goods produced in the *USA* and *ROW* regions.

The presence of these interregional leakages, coupled with intermediate demands and the presence of large government sectors (with homothetic demands), tends to blunt the differences in private household income elasticities of demand reported in Chapter 4. The demand for services is the most elastic, followed by manufacturing and then food. There is considerable variation in the own-income elasticities of demand for food across regions, with that in ROW being most responsive to income. This follows from the fact that per capita income in ROW is considerably lower. Cross-region effects

Table 5.4. ***Equilibrium Income Elasticities of Demand: 3X3 Aggregation***

	PE Closure with Endowment Prices and Regional Incomes Fixed			
qo	y(usa)	y(eu)	y(row)	y(world)
usa_f	0.397	0.015	0.060	0.472
usa_m	0.647	0.051	0.136	0.834
usa_s	0.869	0.019	0.045	0.933
er_f	0.008	0.415	0.055	0.479
eu_m	0.039	0.600	0.189	0.828
eu_s	0.012	0.841	0.085	0.938
row_f	0.013	0.024	0.541	0.578
row_m	0.077	0.100	0.665	0.845
row_s	0.024	0.053	0.864	0.940

are strongest for manufactures, which have substantial trade linkages among regions.

The final column in Table 5.4 shows that impact on regional outputs when *global* incomes increase by 1%. This further blunts the differences across regions. Services outputs increase by .93–.94%, followed by manufactures, .83–.84%, and food, .47–.57%.

Decomposition of aggregate demand elasticities

The aggregate demand elasticities reported in Table 5.3 may also be *decomposed* into their component parts. In this section we develop the analytical formula for this decompositionof the aggregate demand elasticity, denoted: $\varepsilon_{(i,r)(j,s)} = qo(i,r)/pm(j,s)$, and then provide a numerical illustration.

The physical quantity balance for tradeable i in region r is given by:

$$QO(i,r) = QPD(i,r) + QGD(i,r) + QST(i,r) + \sum_{k \in PROD\_COMM} QFD(i,k,r,) + \sum_{t \in REG} QXS(i,r,t). \quad (5.1)$$

This tracks total output to all its potential uses by various agents. Proportionately differentiating (5.1) and multiplying through by the common market price $PM(i,r)$ gives an equation relating the value-weighted change in proportional output to the sum of the weighted proportional changes in demands. Dividing this through by $VOM(i,r) * pm(j,s)$ gives equation (5.2):

Table 5.5. *Decomposition of the Aggregate Demand Elasticity: 3X3 Aggregation*

Agent's Elasticity		Agents' Share of Demand		Contribution to Aggregate Elasticity
$qpd(i,r)/pm(j,s)$	= -0.291	$VDPM(i,r)/VOM(i,r)$	= 0.479	-0.139
$qgd(i,r)/pm(j,s)$	= -1.032	$VDGM(i,r)/VOM(i,r)$	= 0.017	-0.017
$qfd(i,food,r)/pm(j,s)$	= -0.807	$VDFM(i,food,r)/VOM(i,r)$	= 0.310	-0.250
$qfd(i,mnfcs,r)/pm(j,s)$	= -0.057	$VDFM(i,mnfcs,r)/VOM(i,r)$	= 0.010	-0.001
$qfd(i,svces,r)/pm(j,s)$	= -0.101	$VDFM(i,svces,r)/VOM(i,r)$	= 0.112	-0.011
$qfd(i,cgds,r)/pm(i,s)$	= -0.224	$VDFM(i,cgds,r)/VOM(i,r)$	= 0.000	0.000
$qxs(i,r,usa)/pm(j,s)$	= -2.649	$VXMD(i,r,usa)/VOM(i,r)$	= 0.000	0.000
$qxs(i,r,eu)/pm(j,s)$	= -3.614	$VXMD(i,r,eu)/VOM(i,r)$	= 0.013	-0.047
$qxs(i,r,row)/pm(j,s)$	= -3.293	$VXMD(i,r,row)/VOM(i,r)$	= 0.060	-0.198
$qst(i,r)/pm(j,s)$	= 0.000	$VXS(i,r)/VOM(i,r)$	= 0	0.000
$qo(i,r)/pm(j,s)$	= -0.663	$VOM(i,r)/VOM(i,r)$	= 1.000	-0.663

Note: $\epsilon_{(i,r)(j,s)}$ = -0.633; $i = j = food$; $r = usa$.

$$\frac{qo(i,r)}{pm(j,s)} = \frac{VDPM(i,r)}{VOM(i,r)} * \frac{qpd(i,r)}{pm(j,s)} + \frac{VDGM(i,r)}{VOM(i,r)} * \frac{qgd(i,r)}{pm(j,s)}$$
$$+ \sum_{k \in PROD\_COMM} \frac{VDFM(i,k,r)}{VOM(i,r)} * \frac{qfd(i,k,r)}{pm(j,s)}$$
$$+ \sum_{t \in REG} \frac{VXMD(i,r,t)}{VOM(i,r)} * \frac{qxs(i,r,t)}{pm(j,s)} + \frac{VST(i,r)}{VOM(i,r)} * \frac{qst(i,r)}{pm(j,s)}. \quad (5.2)$$

The aggregate demand elasticity, $\varepsilon_{(i,r),(j,s)} = qo(i,r)/pm(j,s)$, on the left-hand side gives the interregional cross-price elasticity. The right-hand side shows the contribution to the aggregate response by different agents that consume the sector's output. The value flows making up these weights may be found in Table 5.1, for $r = usa$. These operate as weights on the individual agents' price elasticities. Relatively elastic agents that consume a higher proportion of the output contribute more to the aggregate demand response.

Table 5.5 presents a numerical illustration of equation (5.2) whereby $i = j = food$ and $r = s = usa$, under the standard GE closure. From Table 5.3 we see that the aggregate, GE, own-price elasticity of demand for US food is equal to –0.663. The last column in Table 5.5 breaks this elasticity into its component parts. The largest contributor is the food sector itself (–0.250 of the total). This is due to the relatively large share of farm and food output used as intermediate inputs in this sector (.31 from column 2 of Table 5.5), and the relatively price-responsive demand in this sector (–0.807 from column 1).

In contrast to the intermediate demands by the food industry, final demands by private households (see the first row in Table 5.5) account for almost half of all sales (agent's share = 0.479) but embody relatively little price responsiveness (agent's elasticity = –0.291), therefore, they contribute only half as much to the GE demand elasticity for food (–0.139 vs. –0.250). Finally, note that the contribution of domestic final demands for US food are eclipsed in column 3 by export demands, which account for –0.245 (= –.047 + –0.198) of the total.

IV Summary

This chapter has demonstrated how the theory, data, and parameters of the standard GTAP framework interact for a particular aggregation, under alternative closure assumptions. The resulting *equilibrium elasticities* are quite informative. For example, when only demand-side forces are considered, the predominant, equilibrium, cross-price relationships in the model are those of intraregional complementarity and interregional substitutability. However, when factor market equilibrium conditions are brought into play, goods become *intraregional substitutes*. Interregional relationships are mixed; like commodities in different regions are substitutes, and other interregional cross-price relationships exhibit complementarity. Finally, each of these equilibrium elasticities may be broken into its component parts. In sum, the computation and scrutiny of equilibrium elasticities is a very useful exercise. Chapter 6 will discuss how to access the software necessary to do this – and many other types of computing with GTAP.

NOTES

1. This template file may be found in the File Transfer Protocol (FTP) site, also accessible via the GTAP Web site, along with existing GTAP aggregations. Readers interested in ordering additional aggregations may contact GTAP staff by sending a message to GTAP@FTP.PURDUE.EDU.
2. A detailed explanation of this procedure used to generate the matrices automatically is given in the Hands-On document (examples 32–39) described in Chapter 6, and available on the Web site.
3. The row and column labels in Table 5.3 need a little explanation. The "*f*" stands for commodity food, "*m*" for *mnfcs*, and "*s*" for *svces*. For example, *usa-f* is an abbreviation for (*food*, *usa*), and *eu-s* is an abbreviation for (*svces*, *eu*).

CHAPTER 6

Implementing GTAP using the GEMPACK Software

Kenneth R. Pearson

I Introduction and overview

The purpose of this chapter is to introduce you to the publicly available software accompanying this book, and to tell you how you can use this software to carry out, on a PC, the applications presented in Part III (Chapters 7–13) of this book. These programs are based on the GEMPACK suite of software (Harrison and Pearson 1994), which is designed specifically for the nonlinear solution of partial and general equilibrium models. The files with which you will work have been specially tailored to the needs of the Global Trade Analysis Project (GTAP), and they offer users a great deal of flexibility, within this standard framework. The software accompanying this book is referred to as the *GTAP Book Version of GEMPACK.*

GEMPACK separates the theory of GTAP (Chapter 2) from the basic data base (Chapter 3) and the behavioral parameters (Chapter 4). All the applications in Part III draw on the same theoretical structure, which we refer to as the "standard GTAP model." Indeed, the software accompanying this book does not permit the user to modify the basic theory.[1] Within this broad structure, however, there is ample flexibility for addressing a wide variety of issues, including: the impact of economic growth on trade and factor markets, regional integration, multilateral trade policy reform, distributional consequences of technological change, implications of environmental policies, and more. Furthermore, as demonstrated in Chapter 5, users can specify alternative model closures that can be useful, both for decomposing the effects of a simulation as well as for capturing different market environments.

As noted in Chapter 5, we never work with the fully disaggregated GTAP data base. It is simply too large. Rather, we strategically aggregate the data base to meet the needs of a particular application. Thus each of the seven applications which follow is based on a different aggregation of the same data base. For this reason, the first thing the reader will want to do is become familiar with the particular aggregation used in an application. This involves examining key shares and summary variables, as well as computing equilibrium elasticities such as those presented in the previous chapter. The procedures for conducting this type of preliminary analysis are described below in section VI. In addition to the standard GTAP data synopsis, users are given the capacity to create their own summary measures. However, it should be noted that users are discouraged from modifying the value flows in the data base, since doing so is very likely to destroy the consistency of the benchmark equilibrium.

In contrast to the value data, the behavioral parameters associated with a GTAP application may be readily modified, adhering to the theoretical restrictions outlined in the model chapter (Chapter 2). Thus, after replicating the results in Part III (see section V below), the reader may examine the sensitivity of model solutions to changes in key parameters. For example, the trade elasticities may be systematically reduced, or increased, as may the elasticities of substitution in production. The user may also alter the degree of intersectoral factor mobility and the sensitivity of international investment to regional rates of return.

You may also construct your own experiments. We recommend that you begin by marginally altering existing applications, thereupon branching out to new applications. However, there is nothing to prevent you from embarking on an entirely different path of enquiry, and we expect that many readers will eventually turn in this direction. At some point, users may feel constrained by the limitations of the standard GTAP model, in which case they may purchase the requisite software for modifying the theory.[2] Finally, readers may also order their own aggregations of the GTAP data base; they may even purchase the full data base, complete with aggregation software (see section II in Chapter 5).[3]

In summary, using the *GTAP Book Version of GEMPACK*, you can

- Examine the data in any of the aggregations used in the applications in Part III.
- Uncover many useful pieces of summary information about these aggregations.
- Replicate the results of the applications in Part III.
- Modify these applications (including changing the closure, shocks, and parameters).
- See how sensitive the results are to the values of various parameters.
- Carry out completely new applications using the standard GTAP model and selected aggregations from Part III of the book.

The purpose of this chapter is to tell you how to do these things.

Instructions for obtaining the software and data accompanying this book are given in section II of this chapter. Detailed instructions for using the software to carry out these tasks are given in sections III to VI of this chapter. These spell out the steps in running the software and give suggestions for hands-on computing you can carry out to familiarize yourself with the software and with GTAP. Further information about the computer version of the standard GTAP model can be found in section VII, and more information about GEMPACK is given in section VIII.

The programs, data, and files accompanying this book are available only for use on a DOS 80386/80486/Pentium PC with a hard disk, at least 8 Mb of RAM (memory), a numeric coprocessor, and version 3.3 or later of DOS.

The theory of the GTAP model (that is, the formulas and equations in Chapter 2) is written down in the TABLO Input file GTAP94.TAB, which is supplied with the *GTAP Book Version of GEMPACK.* Note that, although the equations are written in a linearized form, the software is still able to produce accurate solutions of the nonlinear levels equations of the model [see Hertel, Horridge, and Pearson (1992) and section 4 of Harrison and Pearson (1994)].

II Installing programs, data, and applications files on your PC

To obtain the files you will need a PC that is connected to the World Wide Web and has a Web browser or File Transfer Protocol (FTP) software available. Before attempting to obtain the files, you should first make a new directory (we suggest that you call it \GTAPBOOK) on your PC for the files, and then put all the files in this directory. To do this, use the commands

md \gtapbook
cd \gtapbook

If you have World Wide Web access, you should download all files from

http://www.agecon.purdue.edu/gtap/software/gtapbook.htm

If not, you can use FTP to obtain the files. To do this, first connect to the relevant machine by entering the command

ftp ftp.purdue.edu

When you receive the prompt to indicate that you are connected, you should log in as user "anonymous" and give your Internet address for the password. The sequence of commands for doing this will be similar (but possibly not identical) to the two below shown in boldface. [In this chapter, we use the convention that the text you type in is shown in **boldface sans serif** type. Any text starting with an exclamation mark ! begins a *comment* (which is in *sans serif italics*); you should not type in the exclamation mark or the text that follows it.] You will, of course, need to type in your Internet address instead of the response "<Internet address>" shown below.

login anonymous
<Internet address> *! E.g. Ken.Pearson@BusEco.monash.edu.au*

(Note that all commands below, while connected to this machine *ftp.purdue.edu,* are case-sensitive. So, for example, "login anonymous" is required, and use of a different case such as "LOGIN ANONYMOUS" may fail. Below, all commands are in lowercase.) All the files relating to this book are in a subdirectory called *pub/gtap/book.* To change to this directory, type in the commands

cd pub
cd gtap
cd book

Most of the files are stored in PKZIP archives (which compress the files). To decompress them on your PC, you will need the program PKUNZIP.EXE. To get this to your PC, issue the commands (use lowercase)

binary
get pkunzip.exe *! (This will download PKUNZIP.EXE to your PC)*

Most of the files you need are .ZIP files. To get them all, issue the commands (again in lowercase)

binary
prompt off *! (This may not be necessary.)*
mget *.zip *! (This should download several .zip files.)*

Some of the files are text files (each has the suffix .txt). To get these to your PC, issue the commands

ascii
mget *.txt *! (This should download one or more .txt files)*

Now issue the command

quit

to exit from FTP. The command

dir

on your PC should show you the file PKUNZIP.EXE, several .ZIP files, and one or more .TXT files.

To extract all the files from a .ZIP archive, issue the command

.\pkunzip <archive-name> *! E.g. ".\pkunzip gempie" to extract files in GEMPIE.ZIP*

At this point, simply extract the files in the archives GEMSIM.ZIP, GEMPIE.ZIP, TABLO.ZIP, SEEHAR.ZIP, SLTOHT.ZIP, TMEM.ZIP, TP1010.ZIP, CMF2-01.ZIP, and AGG2-01.ZIP; the others can wait until later. Also, you should read the text file README.TXT, which contains any changes or corrections made since this book was printed.

Memory required for the programs

When you start running a program that has been compiled and linked with the Lahey Fortran compiler (as the executable images supplied here have been), the program displays a box that tells you how much memory is available. All the programs you have obtained for solving GTAP will run when this box shows that at least 6850K (that is, 6850 kilobytes, or about 6.85 megabytes) of memory is available.

You can test how much memory is available to Lahey programs by running the test program TMEM.EXE. Type in

cd \gtapbook
tmem

If the box shows less than 6850K available, you may not be able to run all the programs. You may be able to increase the amount of memory available by removing device drivers and/or caches (such as SMARTDRV.EXE). (You will probably need to edit your AUTOEXEC.BAT and/or CONFIG.SYS files to do this. You will need to reboot, by holding down the **Ctrl**, **Alt**, and **Del** keys simultaneously, for such changes to take effect.) As long as you have 8Mb or more of memory on your computer, you should be able to arrange things so that the Lahey box shows 6850K or more available.

Editing text files

When installing and using the GEMPACK software, you will need to be able to edit text files. This is often best done using a text editor (that is, an editor designed for handling text files exclusively). A text editor, **EDIT**, is supplied with version 5 or later of DOS. There are many other text editors available on DOS machines. Alternatively, you can use a word processor (such as

Microsoft Word or WordPerfect) to edit text files; if so, you must be careful to save the resulting file as a text file.

Changes to the DOS settings

Check the file CONFIG.SYS in your default directory \. Look for the lines

FILES = xx
BUFFERS = yy

If necessary, change these (use your text editor) so that the number xx is at least 40 and yy is at least 10. If either of these lines is not present, add new lines

FILES = 40
BUFFERS = 10

as appropriate. (If you do not have a CONFIG.SYS file, create a new one containing the two lines above.)

If you change CONFIG.SYS, you need to reboot your system (press **Ctrl**, **Alt**, and **Del** simultaneously) before using the software.

Running GEMPACK programs

Under DOS, this is done simply by typing in the name of the program, as in, for example,

gempie

(You will need to be in directory \GTAPBOOK before typing in these commands.[4])

To exit from the program once it has started running, simply type **Control-C** (that is, hold down the **Ctrl** key, which is usually on the left of your keyboard, and, while holding it down, touch the **C** key). This will interrupt the program and return you to the DOS prompt. (You may have to type **Control-C** twice to achieve this.)

III Using the software: An introduction

You can use the software provided

- To carry out simulations with GTAP
- To look at the data in a GTAP data set
- To find out other useful information about the data in a GTAP data set

This section contains an introduction to these different uses of the software. Detailed instructions for running the programs are given. You are encouraged to run the programs, giving the responses indicated below. In doing so, you will learn about the software and about the GTAP model.

The first part of this section contains an introduction to carrying out simulations with GTAP. It is followed by a subsection on how to look at the data and important consequences of it. Here, you will use the 3x3 GTAP data set discussed in Chapter 5. However, the techniques you will learn will apply equally to the larger GTAP data sets used in the applications in Part III of this book.

Carrying out simulations with GTAP

Simulations with GTAP can be carried out in two steps (see Figure 6.1).[5] The first step in a simulation is to run the program TP1010. You should think of this as the computer version of the theory of GTAP (the human-readable version is the TABLO Input file GTAP94.TAB). TP1010.EXE is produced from GTAP94.TAB by running the GEMPACK program TABLO; see section VII below for more information. When running TP1010, you also specify the base data (that is, the GTAP aggregation you are working with), the closure, and the shocks. The output from TP1010 is a so-called Solution file, a binary file containing the results of the simulation, that is, the percentage changes in the endogenous variables as a result of the shocks to the exogenous variables.

Because this Solution file is a binary file, it must be converted to a text file (that is, to human-readable form). This is done by running the GEMPACK program GEMPIE in the second of the two steps. The output from GEMPIE is a so-called GEMPIE Print file that contains the simulation results (that is, percentage changes in the endogenous variables). This file can be printed or viewed in an editor.

An example. We illustrate this by considering a numeraire simulation with the 3x3 aggregation of the GTAP data. In this simulation, the price of savings is increased by 10%. That is, we supply a shock of 10 to the variable *psave*. To carry out this simulation, proceed as follows.

Step 1 **Run the program TP1010** by entering the commands

```
cd \gtapbook
tp1010
```

(The first changes directory into directory \GTAPBOOK. The second starts TP1010.EXE running.) When prompted by the program, give the two responses

```
cmf
num2-01.cmf
```

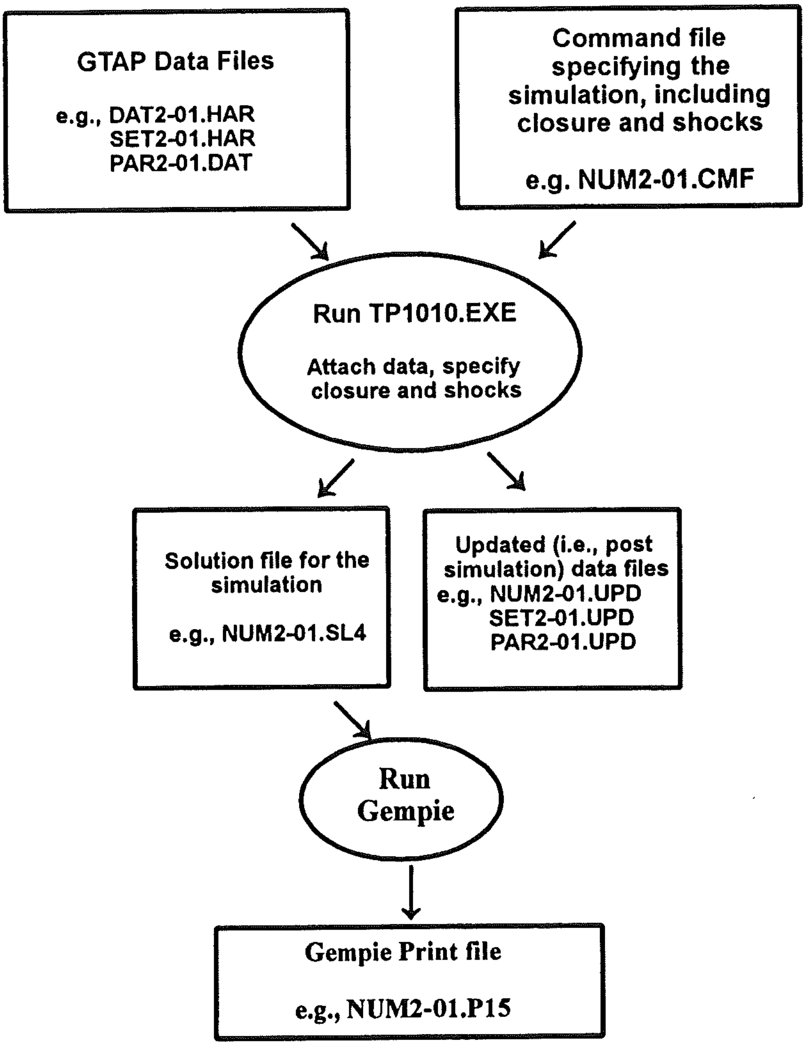

Figure 6.1. Carrying out a simulation with GTAP.

The program will take several minutes to run. It is taking all its input from the GEMPACK Command file NUM2-01.CMF. This file tells which base data to read (that is, which aggregation of the GTAP data to use), which variables are exogenous and which endogenous, and what shocks to give. (We explain the contents of this file below in section IV.) Once the program finishes running, check that the Solution file NUM2-01.SL4 has been created, via the command

```
dir num*.sl4
```

Step 2. **Run the GEMPACK program GEMPIE** by entering

gempie

When prompted by GEMPIE, give the responses below. (The first and fourth are carriage returns. After each response, we have given, in italics, a comment, which starts with an exclamation mark; when running the program, you should not type in the exclamation mark or the comment following it.)

User Input to GEMPIE

`<carriage-return>`	*! Take default options and finish option selection*
`num2-01`	*! Name of Solution file (from Step 1 above)*
`a`	*! Print all endogenous variables*
`<carriage-return>`	*! Accept default name NUM2-01.PI5 for Print file*
`Numeraire shock with 3x3 data`	*! Heading for each page of Print file*
`5`	*! Number of decimal places in the results*

End of User Input to GEMPIE

This should create the GEMPIE Print file NUM2-01.PI5. You can check this via the command

dir *.pi5

This file contains the percentage changes in the endogenous variables of the model resulting from the shocks.

You can look at the results of this simulation by printing NUM2-01.PI5 (if you have a printer attached) or by viewing it in an editor. For example, if you have version 5 or later of DOS, you can view the results by issuing the command

edit num2-01.pi5

(The specific instructions below about keys for moving, searching, and exiting all apply to this DOS editor; if you are using another editor, use the appropriate keys in that editor.) You can move around the file using the **PgDn** and **PgUp** keys. Notice the sections at the start of the file reminding you which variables are exogenous and which are endogenous, and what the shock is.

In this simulation, because the numeraire *psave* has been increased by 10%, you should expect that prices and dollar values will increase by 10% and that quantities will stay unchanged. Is this what you observe? For example, look at the results for variables **qo** (a quantity) and **ps** (a price). [In **edit**, to search for the **qo** results, first go to the top of the file via **Ctrl+Home** (that is, hold down the **Ctrl** key and touch the **Home** key). Then, to search, touch the **Alt** key, then the **s** (search) key, then the **f** (find) key, then type in "**qo (**" as the 4-letter string to search for,[6] and enter a carriage return. This should bring you to the start of the **qo** results.]

To exit from **edit**, touch the **Alt** key, then the **f** (file) key, and then the **x** (exit) key.

Looking at the data in a GTAP data set

You will need to be able to look at the data in a GTAP data set in order to understand simulation results. This involves looking at the data directly and being able to derive important consequences of the data (for example, the share of imports in total household consumption). We have prepared suggestions for hands-on computing to enable you to look at the data in these ways, and to do other GTAP-related computing. These suggestions are contained in a document "Hands-On Computing to Introduce GEMPACK and GTAP" (Pearson 1994); below we refer to this as the *Hands-On document.*

This Hands-On document is one of the files you have installed on your PC. There are two versions of it: first a text version and second a Microsoft Word for Windows version. If you have Microsoft Word for Windows on your computer,[7] you should access the Word version, since it contains boldface and other formatting to make it easier to follow. Otherwise, access the text version (which contains exactly the same information without the formating).

Both of these versions are in the file DOC.ZIP in your \GTAPBOOK directory. To extract the appropriate one, first change directory into \GTAPBOOK via

cd \gtapbook

Then, to access the Word-for-Windows version HANDSON.DOC, first extract it via the command

.\pkunzip doc handson.doc

and then open this file HANDSON.DOC in Microsoft Word for Windows (or another word processor that can read Word for Windows files). Alternatively, to access the text version HANDSON.TXT, first extract it via the command

.\pkunzip doc handson.txt

and then open this file HANDSON.TXT in your favorite editor. (For example, if you have version 5 or later of DOS, issue the command "edit handson.txt.") In either case, you may like to print the Hands-On document. Examples 1–4 in the Hands-On document show you how to look at the data and various shares, etc., directly. We encourage you to work through at least examples 1–8 in the Hands-On document before you attempt to replicate any of the applications in this book (see section V, below).

GEMPACK documentation

GEMPACK is fully documented for users in GEMPACK documents numbered GPD-1, GPD-2, and GPD-3 (see the References section at the end of this chapter). We have tried to make this chapter and the Hands-On document (see above) self-contained. If, however, you feel that you need to look at the GEMPACK documents, there are text versions (which do not include the diagrams or figures) of these on your computer in the files GPD1.ZIP, GPD2.ZIP, and GPD3.ZIP, respectively. To extract these text versions, issue the commands

```
cd \gtapbook
.\pkunzip gpd1 gpd1.txt
```

for GPD-1, and similarly for the other two. Alternatively, you can purchase printed copies of these GEMPACK documents (including diagrams and figures) from the Impact Project (the address is provided in section VIII).[8]

IV Specifying a simulation: An introduction to Command files

Each of the applications in this book was carried out by running the program TP1010, and using a GEMPACK Command file to specify the data, closure, and shocks. The Command file contains all input required by the program TP1010 and also provides a record of the simulation. Below we describe the syntax of these Command files by looking in detail at the file NUM2-01.CMF used in the simulation executed in step 1 in section III, above. The file NUM2-01.CMF is shown in Figure 6.2.

(a) Syntax and Comments in GEMPACK Command files. Any part of a line starting with a single exclamation mark ! is treated as a comment. (We suggest using comments liberally to make Command files self-documenting.) A semicolon ";" ends each statement in a Command file. Any statement can extend over several lines (as in the list of exogenous variables in Figure 6.2). The order of the statements does not matter. Keywords can be abbreviated as long as they remain unambiguous. (For example, "Aux file" can be used as an abbreviation for "Auxiliary files.") Finally, like most GEMPACK files,

```
!________________________num2-01.cmf_________________________
! This GEMPACK command file simulates a numeraire shock in gtap94.tab,
! using the 3x3 data files referred to as aggregation 2-01.
!_____________________________________________________________
!
! Which model
Auxiliary files = tp1010 ;
!
! Original (i.e. pre-simulation) data files
File GTAPSETS = set2-01.har;
File GTAPPARM = par2-01.dat;
File GTAPDATA = dat2-01.har;
!
! Equations file information
Equations File  = TP2-01 ;
        Model = TP1010 ;
        Version = 1 ;
        Identifier = GTAP94.TAB with standard condensation and 3x3 data ;
!
! Closure
Exogenous pop
          psave
          profitslack incomeslack endwslack
          cgdslack saveslack govslack tradslack
          ao af afe ava atr
          to txs tms tx tm
          qo(ENDW_COMM,REG) ;
!
Rest Endogenous ;
!
! Shock
Shock psave = 10 ;
!
! Solution method
Method = Johansen ;
!
Verbal Description =
    ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
   +                       Model TP1010                            +
   +             Experiment NUM2-01: numeraire shock               +
   +                 Solution Method: Johansen                     +
    ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++;
!
! Output File Specification (they are experiment dependent)
 Save Environment File   tp2-01 ;
Solution          File = num2-01 ;
Log               File = num2-01.LOG ;
!
! Updated (i.e. post-simulation) data files
Updated file GTAPSETS = set2-01.upd;
Updated file GTAPPARM = par2-01.upd;
Updated file GTAPDATA = num2-01.upd;
!
Display file = tp2-01.dis ;
!
! Options
Extrapolation accuracy file = YES ;
CPU = yes ;
! Next needed if reusing pivots is to succeed in multistep sim
Iz1 = no ;
!_____________________________End of file____________________
```

Figure 6.2. The GEMPACK Command file NUM2-01.CMF.

Command files are not case-sensitive. You can put "Johansen" or "johansen." (Command files are case-sensitive only for file names on systems such as Unix, on which file names are case-sensitive.)

(b) Which model. The statement

```
Auxiliary files = tp1010 ;
```

tells the program TP1010 to use the Auxiliary files TP1010.AXS and TP1010.AXT. These are computer representations of the theory in GTAP94.

TAB as implemented with the standard GTAP condensation. (That is, with the omissions and backsolves indicated in section VII, below.)

(c) Base data. The statements

```
File GTAPSETS = set2-01.har ;
File GTAPDATA = dat2-01.har ;
File GTAPPARM = par2-01.dat ;
```

specify the names of the three data files used in this simulation. These contain, respectively, the set information, the global data base, and the parameters for the 3x3 GTAP data set (aggregation number 1). (Other aggregations of the GTAP data are used in the applications in this book; see section V below for details.)

(d) Closure. This is specified by the statements

```
Exogenous pop
          psave
          profitslack incomeslack endwslack
          cgdslack saveslack govslack tradslack
          ao af afe ava atr
          to txs tms tx tm
          qo(ENDW_COMM,REG) ;
Rest Endogenous ;
```

which list the exogenous variables and state that all other variables are endogenous. (Alternatively, you could list the endogenous variables and state that the remainder are exogenous, or even list all exogenous and all endogenous variables.)

(e) Shock. This is specified by the statement

```
Shock psave = 10 ;
```

which indicates that variable *psave* (the price of capital goods supplied to savers, which is the numeraire of GTAP) is to be increased by 10%.

(f) Solution file and verbal description. The Solution file name is specified via the statement

```
Solution File = num2-01 ;
```

TP1010 automatically adds the suffix ".SL4" so that the full name is NUM2-01.SL4.

The verbal description is specified by the statement

```
Verbal Description =
 +++++++++++++++++++++++++++++++++++++++++++++++++
+                  Model TP1010                    +
+        Experiment NUM2-01: numeraire shock       +
+            Solution Method: Johansen             +
 +++++++++++++++++++++++++++++++++++++++++++++++++;
```

This verbal description (five lines of text) is put on the Solution file and is echoed when the Solution file is accessed, so that it appears on the GEMPIE Print file.

(g) Updated (i.e., postsimulation) data. The names of the updated files are specified by the statements

```
Updated file GTAPSETS = set2-01.upd;
Updated file GTAPPARM = par2-01.upd;
Updated file GTAPDATA = num2-01.upd;
```

Of these, the only interesting one is the updated global data file NUM2-01.UPD, which contains the global data as it would be once the numeraire has been increased by 10%. The updated set information and parameters files are redundant (since they will be identical to the original ones), but the software requires that names be given for them.

(h) Solution method. This is specified by the statement

```
Method = Johansen ;
```

which tells TP1010 to use Johansen's method. While Johansen's method is satisfactory for this numeraire simulation (which is essentially a linear perturbation of the economy), if you want accurate solutions of the underlying nonlinear equations of the model, it is usually necessary to use Gragg's method (the default in GEMPACK) or Euler's method. For example, to use Gragg's method and to extrapolate from 2,4,6-step calculations, replace the above statement by[9]

```
Method = Gragg ;
Steps = 2 4 6 ;
```

(i) Other information. The statements

```
Equations File = TP2-01 ;
       Model = TP1010 ;
       Version = 1 ;
       Identifier = GTAP94.TAB with standard conden-
       sation and 3x3 data ;
```

specify the name of the so-called Equations file and associated information. This is required information whenever you carry out a simulation (unless you start from an existing Equations file). The statement

```
Save Environment File tp2-01 ;
```

tells TP1010 to save the closure on a so-called Environment file. Then, to specify this closure in another Command file, you could use the statement

```
Use Environment file tp2-01 ;
```

which would save having to list the exogenous variables there. The statement

```
Log File = num2-01.LOG ;
```

tells TP1010 to record all screen output in the LOG file NUM2-01.LOG. After the run, you can look at this LOG file to check that things went as expected. The statement

```
Display file = tp2-01.dis ;
```

names the display file produced. The statements

```
Extrapolation accuracy file = YES ;
CPU = yes ;
```

tell TP1010 to produce a so-called Extrapolation Accuracy file and to report CPU (that is, processing) times. If you employ a multistep (i.e., nonlinear) solution procedure, the Extrapolation Accuracy file contains information about the accuracy of the results. The statement

```
Iz1 = no ;
```

is added because we know that it speeds up multistep calculations with GTAP. This is a rather technical point that you shouldn't worry about until you are very experienced with GEMPACK and its solution process.

Other Command files you might like to look at are TMSEU.CMF and TMSEUN.CMF (see examples 20–24 in the Hands-On document).

Specifying components of a variable

Individual components of a variable can often be specified using the element name(s), as in, for example, **qo("food","usa")**. Groups of components can often be expressed in a similar way, as in, for, example, **qo("food",REG)**.

Sometimes you will need to specify component numbers or to understand output from a program given in terms of component numbers. If so, the order of the components is specified by the rule that *the first index varies fastest, followed by the second index, and so on.*

Consider the 3x3 aggregation in which **TRAD_COMM = (food, mnfcs, svces)**, and **REG = (USA, EU, ROW)**. Consider variable *qxs*(**i,r,s**), **i** in TRAD_COMM, and **r,s** in REG [exports from r to s]. In this case, **i** varies fastest, **r** next fastest, **s** most slowly. There are 3*3*3=27 components. This gives rise to the following ordering for *qxs*:

component number	component
1	*qxs*("food","USA","USA")
2	*qxs*("mnfcs","USA","USA")
3	*qxs*("svces","USA","USA")
4	*qxs*("food","EU","USA") (etc)
9	*qxs*("svces","ROW","USA")
10	*qxs*("food","USA","EU")
11	*qxs*("mnfcs","USA","EU") (etc)
27	*qxs*("svces","ROW","ROW")

V Carrying out the applications simulations

Below you will find a list of the seven applications in Part III (Chapters 7–13) of this book. Next to each application is the number identifying the aggregation of the GTAP data base used in the application. (Aggregation number 1 is the 3x3 data used above. Aggregation number 2 is employed in Chapter 14 of this book.)

Identifying number of aggregation	Topic
3	Growth and Wages (Chapter 7)
4	Agricultural Liberalization (Chapter 8)
5	APEC Liberalization (Chapter 9)
6	MFA Liberalization (Chapter 10)
7	Climate Change (Chapter 11)
8	Environmental Policy (Chapter 12)
9	Technical Change (Chapter 13)

Associated with each application are two .ZIP files, called **AGG2-0X.ZIP** and **CMF2-0X.ZIP** (where **X** is replaced by the identifying number of the aggregation used in the topic). For example, associated with the application "Growth and Wages" in Chapter 7 are the two files AGG2-03.ZIP and CMF2-03.ZIP. (The files AGG2-0X.ZIP and CMF2-0X.ZIP should be in directory \GTAPBOOK.) The file **AGG2-0X.ZIP** contains compressed versions of the four files

DAT2-0X.HAR Global data file
SET2-0X.HAR Set information
PAR2-0X.DAT Parameters
AGG2-0X.TXT Mapping file describing the aggregation

The file **CMF2-0X.ZIP** contains the Command files and any associated shocks files used in reproducing the results in the application.

If you wish to run the simulations for any of these applications, you will first need to uncompress the files. First change directory into \GTAPBOOK and then run PKUNZIP to uncompress the files. Use the following commands (in which you should replace **X** by the relevant number 3, . . . , 9).

```
cd \gtapbook
.\pkunzip agg2-0x     ! example: .\pkunzip agg2-03
.\pkunzip cmf2-0x     ! example: .\pkunzip cmf2-03
```

Each of the CMF2-0X.ZIP files contains a README file called **READ2-0X.ME**. This file contains instructions and advice about carrying out the simulations for the particular application. You should always read this file before starting to replicate the results in an application.

Example

Below we show you how to replicate the results of one of the simulations in the Technical Change application in Chapter 13. This simulation, which looks at the effects of a 2% rate of total factor productivity growth in Australasian crops, uses the data in GTAP aggregation number 9. To extract the data files for this aggregation, enter the commands

```
cd \gtapbook
.\pkunzip agg2-09
```

First check the size of this aggregation by examining the set information file SET2-09.HAR following the method in example 1 of the Hands-On document. You will see that this aggregation recognizes five tradeable commodities (crops, livestock, fish & food, manufactures, and services) and six regions (North America, EU, Australasia, East Asia, Southeast Asia, and ROW).

To carry out the simulation, follow the steps in Figure 6.1. The Command file to use is C2-09E1.CMF, which can be extracted from CMF2-09.ZIP via the command

.\pkunzip cmf2-09

You might like to look at this file C2-09E1.CMF to see the shock, which is an increase of 2% to **ao("crops","AustrNZ")**.
First run TP1010 by typing

tp1010

and then give the two responses

cmf
c2-09e1.cmf

When TP1010 finishes running, check that the Solution file C2-09E1.SL4 has been created via the command

dir c2-09*.sl4

Then run GEMPIE by typing

gempie

Respond as in step 2 in section III above, but replace "num2-01" with "c2-09e1" as the Solution file name, and enter a suitable heading for each page of the Print file.

The first two entries in the first column of Table 13.3 in Chapter 13 give the effects of this shock on Australasian crops and livestock output. To check these values, look in the Print file C2-09E1.PI5, find the output results (the variable is **qo**), and verify that: (1) output of crops in Australasia increases by 2.32%, and (2) output of livestock in Australasia decreases by 0.04%. You can follow a similar procedure to replicate other results in this chapter (or other chapters) in Part III of the book.

Modifying the applications

It is one thing to reproduce the results of the applications in this book, but it may be more interesting and instructive to carry out other simulations of your own choosing. With the software you have obtained from the FTP site, you can vary the shocks, closure, and/or solution method used. We say something about each of these options below. Note that complete documentation of the syntax allowed in Command files is given in Appendix A.1 of GEMPACK document GPD-1; however, the examples given above in section IV will probably cover most (ideally, all) of the cases of relevance to you. If you edit a Command file in a word processor (as opposed to a text editor), remember to save the new file as a text file.

Varying the shocks, closure, and/or solution method. To do any of these, all you need to do is to make the obvious changes to the Command file used to run TP1010. For example, to change the shocks, just change the shock statements in the Command file; to change the closure, change the exogenous statements. You might like to see how changing from Gragg's method to the midpoint or Euler's method changes the accuracy of the extrapolated results for the shock given in TMSEUN.CMF (see examples 23–24 in the Hands-On document). (The statements "Method = midpoint;" or "Method = Euler;" instead of "Method = Gragg;" will change the solution method to the midpoint or Euler's method, respectively.)

Varying the data. You can modify the parameters by editing the appropriate PAR2-0X.DAT file. (It is a text file.) For example, if you wish to examine the sensitivity of any of the application results in Part III to the parameter values used, you can systematically vary the parameters of interest and recompute the simulation results.

However, we do not recommend modifying the global data in any of the GTAP aggregations, since this is likely to destroy the consistency of the benchmark equilibrium.

Varying the theory and condensation of the model. The theory of the GTAP is contained in the TABLO Input file GTAP94.TAB. (You might like to look at this file to see how the GTAP equations in Chapter 2 have been written in the algebraic syntax used in TABLO Input files.) The standard condensation used to generate the program TP1010 and the Auxiliary files TP1010.AXS and TP1010.AXT files is that given by running TABLO taking all inputs (in particular, omissions and backsolves) from the Stored-input file TP1010TG. STI . (See section VII below for more details.) With the software provided in the *GTAP Book Version of GEMPACK*, you cannot change the theory or condensation. (To do so, you would need a Source-code version of GEMPACK or a larger Executable-Image version.)

Errors you may encounter while running GEMPACK programs

Most error messages from the programs should be self-explanatory. For example, if you choose an invalid closure when you carry out a simulation, this is likely to show up when the relevant matrix (called the left-hand-side matrix) is reported as being structurally or numerically singular. However, due to the rounding that inevitably occurs whenever a large arithmetic calculation is carried out on a computer, the software is not always able to distinguish between a singular matrix and one that is nearly singular. Accordingly, invalidity of a closure may not always be identified by the program. It should, however, be evident in the simulation results (which will probably contain implausibly large movements).

If you receive warnings about the accuracy of the results, you should check carefully to ensure that you are using a valid closure. (Note that warnings about a "possibly ill-conditioned matrix" can usually be ignored with GTAP.)

Dimension limits may be exceeded. Each of the programs in the *GTAP Book Version of GEMPACK* (e.g., SEEHAR.EXE and GEMSIM.EXE) can handle only limited model sizes. They have been dimensioned so as to be able to carry out most (ideally, all) tasks associated with aggregations up to 10 regions and 10 tradeable commodities that you may wish to use them for. It is, however, possible that you may ask them to carry out a calculation that exceeds these limits. If so, you will see a message similar to the following.

```
You have exceeded the size limits of
the GTAP Book version of GEMPACK.
(To complete your current task, you
would need a source-code version of GEMPACK.)
```

With the GTAP book version of the software, your best alternative is to find another way of carrying out the same task. (The only other alternative is to obtain a source-code version of GEMPACK; this allows you to reconfigure programs to take advantage of all memory on your computer.)

If a multistep simulation does not converge. Gragg's method or the midpoint method converges much more quickly than Euler's method for many simulations. (That is, they produce much more accurate results for the same number of steps.) However, it is known that Gragg's method and the midpoint method are not suitable for some simulations; see part E of the Hands-On document for details.

VI Data reporting and equilibrium elasticities

Data reporting

The three TABLO Input files GTAPCHK.TAB, SHOCKS.TAB, and GTAPVOL.TAB are important adjuncts to the GTAP model. GTAPCHK.TAB is used to report many useful pieces of information from a GTAP data set. SHOCKS.TAB is used to calculate the distortions (such as import tariffs and output subsidies) in a GTAP data set, and to write the shocks required to eliminate these distortions. GTAPVOL.TAB is used to report volume changes (rather than percentage changes) implied by a GTAP simulation.

Information about a GTAP data set via GTAPCHK.TAB. See examples 5–8 of the Hands-On document for details about GTAPCHK. It is easy to modify GTAPCHK to add extra calculations and reports. Examples 9–11 in the Hands-On document show how to do this.

Preparing shocks using SHOCKS.TAB. For the use of SHOCKS.TAB, see examples 12 and 13 in the Hands-On document.

Reporting volume changes via GTAPVOL. When you carry out a simulation using GTAP, the Solution file (or GEMPIE Print file) give information about percentage changes in quantity indices. (For example, the **qo** results give information about changes in the outputs of different commodities in the different regions.) The TABLO Input file GTAPVOL.TAB has been designed to report the corresponding **changes** (rather than percentage changes) in some of these volumes. See examples 28–31 in the Hands-On document for details about the use of GTAPVOL.

Computing equilibrium elasticities (see Chapter 5)

You can compute the equilibrium elasticities for the 3x3 data set described in Chapter 5. To do so, simply follow the steps in examples 32–39 in the Hands-On document. Before you try these examples, you will first need to extract SAGEM.EXE from its archive via the commands

```
cd \gtapbook
.\pkunzip sagem
```

VII Producing TP1010.EXE from the TABLO Input file GTAP94.TAB

Condensation and omission of variables

The theory of the GTAP model (as described and used in this book) is contained in the TABLO Input file GTAP94.TAB. This allows different aggregations with up to 10 regions and up to 10 tradeable commodities.[10] In order to solve the model on an 8Mb PC, a particular implementation, referred to as **TP1010**, is supplied. In this implementation[11]

(a) certain policy variables have been **omitted**. This means that these variables are effectively exogenous but cannot be shocked. (When you work with this implementation, it is as if these variables had never been present in the model.) The variables omitted are:

tf tpm tpd tgm tgd tfm tfd

(b) certain variables have been selected for **backsolving**. This means that these variables are hard-wired as endogenous. When you run a simulation, you can obtain results for these variables. However, they cannot be set exogenous in this implementation. The variables that are backsolved for are:

pfd ppm pfm pms pfob pcif pf ppd pgm pgd qfm qfd
pva qfe qva qf
pgov qg pg qgm qgd qp qpd qpm

You can look in GTAP94.TAB to find out more about these variables.

The computer version of TP1010 consists of the file TP1010.EXE and the two **Auxiliary files** TP1010.AXS and TP1010.AXT. These files, which should be in directory \GTAPBOOK on your computer, were produced by running the GEMPACK program TABLO taking inputs from the Stored-input file TP1010TG.STI.[12] The file TP1010TG.STI, which should also be in directory \GTAPBOOK on your computer, includes instructions to omit and to backsolve, as indicated above.

The full GTAP94.TAB has approximately 14,400 equations and 22,600 variables for a 10x10 aggregation of the model. The condensation in TP1010TG .STI omits approximately 2,900 of these variables and leaves a condensed system of about 3,150 equations in about 8,460 variables. Thus, with a 10x10 aggregation, TP1010 solves a system of about 3,150 linear equations in the middle of each step of a multistep calculation. During each step, about 260 variables are backsolved for. See section 3.9 of GPD-1 for more about condensation and section 4.2 of GPD-1 for information about how a multistep calculation is done.

Levels and linearized equations

The TABLO Input file GTAP94.TAB has all its EQUATIONs expressed in linearized form. GEMPACK also allows *levels* EQUATIONs in TABLO Input files, and a mixture of levels and linearized equations can be given in such files. For example, see the TABLO Input file SJ.TAB for the Stylized Johansen model, which is discussed and given in full in sections 3.1 to 3.3 of GPD-1. Detailed advice about linearizing equations can be found in Appendix A of GPD-2.

VIII GEMPACK

GEMPACK is a suite of general purpose software especially designed for implementing and solving general and partial equilibrium models. The software can handle a wide range of economic behavior, including forward-looking behavior in intertemporal models. GEMPACK is used to solve many different models besides GTAP [see, for example, the models listed in section 2.6 of Harrison and Pearson (1994)]. Part F of the Hands-On document gives information about some available models other than the GTAP.

An introduction to the current release of GEMPACK, Release 5.1, and to the different versions of GEMPACK can be found in Harrison and Pearson (1994) and also in sections 1.1-1.3 of GPD-1. Information about GEMPACK can be obtained from

The GEMPACK Manager
Centre of Policy Studies and Impact Project
Monash University
Clayton 3168, Australia
Telephone: +613-9905-5484
Fax: +613-9905-5486
email: impact@vaxc.cc.monash.edu.au

Programs provided in the GTAP Book Version of GEMPACK

GEMPIE. Use this to convert a Solution file to human-readable form. (See Figure 6.1.)

TP1010. Use this to carry out simulations with the GTAP. (See section VII above for the procedure for producing TP1010.EXE.)

TABLO. Use this to process TABLO Input files, both those for models (such as GTAP94.TAB–see section VII above) and those for carrying out data manipulation tasks (such as GTAPCHK.TAB–see section VI above). [See step 1 in figure 3.3 in Harrison and Pearson (1994) or in figure 2.1 in GPD-1.]

SEEHAR. Use this to look at the data in GEMPACK Header Array files including the set information and global data files in a GTAP data set. See examples 1, 2, and 4 in the Hands-On document for the use of SEEHAR.

GEMSIM. Use this to carry out the calculations in data manipulation TABLO Input files (such as GTAPCHK.TAB–see section VI above). It can also be used to solve (small) models (see section 2.1 of GPD-1).

SLTOHT. Use this to convert Solution files to other forms, notably to Header Array files. To see how SLOTHT is used, see the GTAPVOL part of section VI above.

SAGEM. Use this to calculate several Johansen solutions in one run, as in, for example, its use in computing several equilibrium elasticities (see section VI above). In producing several solutions in one run, SAGEM takes only about as long as TP1010 takes to do one step of a multistep calculation. Of course, Johansen results are not accurate solutions of the underlying nonlinear equations of the model, so they must be used with care. But they can be helpful in forming preliminary ideas about a new scenario.

The Harwell subroutines

The speed with which GEMPACK programs such as TP1010, GEMSIM, and SAGEM solve the system of linear equations on each step of a multistep simulation is due to the efficiency of the Harwell sparse linear equations routines MA28 [see Duff (1977)] developed by AEA Technology at Harwell, UK.[13]

NOTES

1. Readers with access to a source-code version of GEMPACK [see section 11 of Harrison and Pearson (1994)] can modify the standard model, if they wish.
2. The theory can be modified using a source-code version of GEMPACK. Enquiries about purchasing such a version should be addressed to the Impact Project, whose address is given in section VIII.
3. Inquiries regarding purchase of the GTAP data base should be directed to GTAP@FTP.PURDUE.EDU. Additional information is available on the GTAP Web site.
4. (a) If you want to be able to run the programs from other directories, you will need to add directory \GTAPBOOK to your DOS PATH. To do this, edit the file AUTOEXEC.BAT, which is usually in your default directory \ . You should add \GTAPBOOK to the PATH statement in that file. For example, if you find a line
   PATH = C:\;C:\DOS;
   add "C:\GTAPBOOK;" at the end (be careful to separate directory names by semicolons ";") to make it
   PATH = C:\;C:\DOS;C:\GTAPBOOK;
   (You will need to reboot your PC to put such a change into effect.)
   (b) If your PC runs under Windows, you will need to run the software in a DOS box.
5. These two steps are those called steps 2 and 3 in figure 3.3 in Harrison and Pearson (1994). Step 1 in that figure has already been carried out for you: see section VII.
6. The four letters are **q**, then **o**, then a **space**, and finally an opening parenthesis (. The space and parenthesis (are added to bypass several occurrences of **qo** earlier in the file.
7. You will need version 2.0 or later of Word for Windows or another word processor that can read Word for Windows 2.0 files (such as version 5.1 or later of WordPerfect).
8. At the time of publication of this book, the cost is $A70 in Australia, New Zealand, or Papua New Guinea or $US70 elsewhere. (This cost includes postage by airmail.)
9. Since Gragg is the default method in GEMPACK, the statement "Method = Gragg ;" could be omitted.

10. To work with more than 10 regions or more than 10 tradeable commodities, you would need a source-code version of GEMPACK and an aggregation of the GTAP data base not provided with this book.
11. Of course, other implementations could be made using a source-code version of GEMPACK. However, you cannot make other implementations using the software accompanying this book.
12. See step 1 in figure 3.3 of Harrison and Pearson (1994) or in figure 2.6.1 in GPD-1.
13. MA28 is just one of the large number of general purpose routines in the Harwell Subroutine Library that can be used to carry out a wide range of numerical calculations (including matrix calculations, solving differential equations, statistical calculations, numerical integration, root finding, and so on). For more information about the software in this library, contact Harwell Subroutine Library, AEA Technology, 329 Harwell, Didcot, Oxfordshire OX11 0RA, UK.

REFERENCES

Duff, I. S. (1977) *MA28 A Set of FORTRAN Subroutines for Sparse Unsymmetric Linear Equations*, Harwell Report R.8730 (HMSO, London), p. 104.

Harrison, W. Jill, and K. R. Pearson (1994) *Computing Solutions for Large General Equilibrium Models Using GEMPACK*, Centre of Policy Studies and Impact Project Preliminary Working Paper No. IP-64, Monash University, June. [Revised version to be published in *Computational Economics* in 1996.]

Hertel, T. W., J. M. Horridge, and K. R. Pearson (1992) "Mending the Family Tree: A Reconciliation of the Linearization and Levels Schools of Applied General Equilibrium Modeling," *Economic Modelling* 9:385–407.

GEMPACK documents

GPD-1, *An Introduction to GEMPACK*, 2nd edition, April 1994, pp. 252ff.

GPD-2, *User's Guide to TABLO, GEMSIM and TABLO-generated Programs*, 2nd edition, April 1994, pp. 138ff.

GPD-3, *How to Create and Modify GEMPACK Header Array Files Using the Program MODHAR*, 3rd edition, April 1993, pp. 27ff.

Hands-On document

Pearson, K. R. (1994) "Hands-On Computing to Introduce GEMPACK and GTAP." [This is the document in the files HANDSON.TXT and HANDSON.DOC available via FTP–see section III in the text of this chapter. This is referred to as the "Hands-On document" in the text.]