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A SAM Based Global CGE Model using GTAP Data

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Abstract

This paper provides a technical description of a global computable general equilibrium (CGE) model that is calibrated from a Social Accounting Matrix (SAM) representation of the Global Trade Analysis Project (GTAP) database. A distinctive feature of the model is the treatment of nominal and real exchange rates and hence the specification of multiple numéraire.

Keywords: Computable General Equilibrium; GTAP.

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1. INTRODUCTION

This paper provides a technical description of a variant of a Social Accounting Matrix (SAM) based Global Computable General Equilibrium (CGE) model that has been calibrated using data derived from the Global Trade Analysis Project's (GTAP) database. The model is a member of a family of CGE models that model trade relationships using principles described in the 1-2-3 model (de Melo and Robinson, 1989; Devarajan, *et al*., 1990). More specifically this model is a direct descendant of an early US Department of Agriculture model (see Robinson *et al*., 1990) and a model that was developed to evaluate the NAFTA (Robinson *et al*., 1993). However numerous features of this model stem from other developments in CGE modelling over the last 10 years; some of these sources of inspiration are direct and easily identified, e.g., the IFPRI standard model (Lofgren *et al*., 2002) and the PROVIDE Project model (McDonald, 2003), others are indirect and easily identified, e.g., the GTAP model (Hertel, 1997), while others are both direct and indirect but less easily identified. In addition the model owes a lot to the development of the SAM approach to national accounting, e.g., Stone (1962a and b) and Pyatt (1991), and the SAM approach to modelling, e.g., Pyatt (1987), Drud *et al*., (1986).

The underlying approach to multi-region modelling for this CGE model is the construction of a series of single country CGE models that are linked through their trading relationships. As is common with all known CGE models the price system(s) in the model are linear homogenous and hence the focus is upon movements in relative, rather than absolute, prices. Consequently each region in the model has its own numéraire price, typically the consumer price index (CPI), and a nominal exchange rate, while the model as a whole requires a numéraire, typically the exchange rate of a reference region. As such this model contains a fundamentally different philosophical approach to global modelling to that found in the GTAP model.[1] Behind this difference lies a deep theoretical debate about how comparative static and finite horizon dynamic CGE models should value transfers associated with the capital account of the balance of payments (see Robinson, 2004).

The rest of this paper is organised as follows. Section 2 reviews the data used in the model; this section also provides a brief description of how the data were transformed from the GTAP database into a SAM. This is followed in section 3 by a descriptive overview of the

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[1] The GTAP model does not contain nominal exchange rates and has a single global numéraire.

model and then, in section 4, by a formal description of the model's equations. The description in section 4 is based upon a default setting for the model closure rules; one of the model's key features is the flexibility of the closure rules and consequently section 5 considers the alternatives built into the model's basic structure. All global CGE models are large and therefore present a series of potential implementation problems; section 6 briefly reviews some of the programmes that have been developed to support the basic model and provides some guidelines for use of this class of model. The paper ends with some concluding comments that primarily focus upon planned model developments.

2.   MODEL DATA

The data used in the model were derived from the GTAP database (see Hertel, 1997) using a three dimensional Social Accounting Matrix (SAM) method for organising the data. Details of the method used to generate a SAM representation are reported in McDonald and Thierfelder (2004a) while a variety of reduced form representations of the SAM and methods for augmenting the GTAP database are reported in McDonald and Thierfelder (2004b) and McDonald and Sonmez (2004) respectively.[2] Detailed descriptions of the data are provided elsewhere so the discussion here is limited to the general principles.

GLOBAL SOCIAL ACCOUNTING MATRIX

The Global SAM can be conceived of as a series of single region SAMs that are linked through the commodity trade accounts; this is particularly valid in the context of the GTAP database since the ONLY way in which the regions are linked directly in the database is through commodity trade transactions although there are some indirect links through the demand and supply of trade and transport services. Specifically the value of exports valued free on board (fob) from source *x* to destination *y* must be exactly equal to the value of imports valued fob to destination *y* from source *x*, and since this holds for all commodity trade transactions the sum of the differences in the values of imports and exports by each region must equal zero. However the resultant trade balances do not fully accord with national accounting conventions because other inter regional transactions are not recorded in the database (see McDonald and Sonmez, 2004). A description of the transactions recorded in a representative SAM for a typical region in the database is provided in Table 1.

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[2]   The GAMS code required for these different methods of representing the GTAP database are freely available.

A SAM is a transactions matrix; hence each cell in a SAM simply records the values of the transactions between the two agents identified by the row and column accounts. The selling agents are identified by the rows, i.e., the row entries record the incomes received by the identified agent, while the purchasing agents are identified by the columns, i.e., the column entries record the expenditures made by agents. As such a SAM is a relatively compact form of double entry bookkeeping that is complete and consistent and can be used to present the National Accounts of a country in a single two-dimensional matrix (see UN, 1993, for a detailed explanation of the relationship between conventional and SAM presentations of National Accounts). A SAM is complete in the sense that the SAM should record ALL the transactions within the production boundary of the National Accounts, and consistent in the sense that income transactions by each and every agent are exactly matched by expenditure transactions. A fundamental consequence of these conditions is that the row and column sums of the SAM for each region must be identical, and hence the SAM provides a complete characterisation of current account transactions of an economy as a circular (flow) system. In the context of a global SAM the complete and consistent conditions need extending to encompass transactions between regions; this simply requires that each and every import transaction by a region must have an identical counterpart export transaction by another region. This is enough to ensure that the resultant global SAM provides a characterisation of current account transactions of the global economy as a circular (flow) system.

Table 1 **Social Accounting Matrix for a Region in the Global Social Accounting Matrix**

	Commodities	Activities	Factors	Households	Government	Capital	Margins	Rest of World	Totals
Commodities	0	Combined Intermediate Use Matrix	0	Private Consumption	Government Consumption	Investment Consumption	Exports of Margins (fob)	Exports of Commodities (fob)	Total Demand for Commodities
Activities	Domestic Supply Matrix	0	0	0	0	0	0	0	Total Domestic Supply by Activity
Factors	0	Expenditure on Primary Inputs	0	0	0	0	0	0	Total Factor Income
Households	0	0	Distribution of Factor Incomes	0	0	0	0	0	Total Household Income
Government	Taxes on Commodities	Taxes on Production	Direct/Income Taxes	Direct/Income Taxes	0	0	0	0	Total Government Income
Capital	0	0	Depreciation Allowances	Household Savings	Government Savings	0	Balance on Margins Trade	Foreign Savings	Total Savings
Margins	Imports of Trade and Transport Margins	0	0	0	0	0	0	0	Total Income from Margin Imports
Rest of World	Imports of Commodities (fob)	0	0	0	0	0	0	0	Total Income from Imports
Totals	Total Supply of Commodities	Total Expenditure on Inputs by Activities	Total Factor Expenditure	Total Household Expenditure	Total Government Expenditure	Total Investment	Total Expenditure on Margin Exports	Total Expenditure on Exports	

Given these definitions of a SAM the transactions recorded in a SAM are easily interpreted. In Table 1 the row entries for the commodity accounts are the values of commodity sales to the agents identified in the columns, i.e., intermediate inputs are purchased by activities (industries etc.,), final consumption is provided by households, the government and investment demand and export demand is provided by the all the other regions in the global SAM and the export of margin services. The commodity column entries deal with the supply side, i.e., they identify the accounts from which commodities are purchased so to satisfy demand. Specifically commodities can be purchased from either domestic activities – the domestic supply matrix valued inclusive of domestic trade and transport margins – or they can be imported – valued exclusive of international trade and transport margins. In addition to payments to the producing agents – domestic or foreign – the commodity accounts need to make expenditures with respect to the trade and transport services needed to import the commodities and any commodity specific taxes.

The GTAP database provides complete coverage of bi lateral transactions in commodities valued free on board (fob) but only provides partial coverage of transactions in trade and transport margins. Specifically the imports of trade and transport margins by each region are directly associated with the imports of specific commodities, hence for each commodity import valued fob the source and destination regions are identified and the value of each trade and transport margin service used is identified. The sum of the values of trade and transport services and the fob value of the commodity import represent the carriage insurance and freight (cif) paid value of each imported commodity. But the source regions of the trade and transport services are NOT identified, and similarly the values of exports of trade and transport services by a region do NOT identify the destination regions. To overcome this lack of information an artificial region called Globe is included in the database. This region collects together all the exports of trade and transport services by other regions as its imports and then exports these to other regions to satisfy there demand for the use of trade and transport services associated with commodity imports. By construction the value of imports by Globe for each and every trade and transport margin service must exactly equal the value of exports for the corresponding trade and transport service. However this does not mean that the trade balance between Globe and each and every region must exactly balance, rather it requires that the sum of Globe's trade balances with other regions is exactly equal to zero.

An important feature of the construction of a SAM can be deduced from the nature of the entries in the commodity account columns. By definition the columns and row totals must equate and these transaction totals can be expressed as an implicit price times a quantity and the quantity of a commodity supplied must be identical to the quantity of a commodity demanded. The column entries represent the expenditures incurred in order to supply a commodity to the economy and hence the implicit price must be exactly equal to the average cost incurred to supply a commodity. Moreover since the row and column totals equate and the quantity represented by each corresponding entry must be same for the row and column total the implicit price for the row total must be identical to average cost incurred to supply the commodity. Hence the column entries identify the components that enter into the formation of the implicit prices in the rows, and therefore identify the price formation process for each price in the system. Typically a SAM is defined such that the commodities in the rows are homogenous and that all agents purchase a commodity at the same price.

Total income to the activity accounts is identified by the row entries. In the simple representation of production in the GTAP database each activity makes a single commodity and each commodity is made by a single activity, which means that the domestic supply matrix is a square diagonal matrix. The expenditures on inputs used in production are recorded in the activity columns. Activities use intermediate inputs, which in this version of the database are record as composites of domestically produced and imported commodities, primary inputs and pay taxes on production. For each region the sum of the payments to primary inputs and on production taxes by activity is equal to the activity's contribution to the value added definition of GDP while the sum over activities equals the region's value added measure of GDP.

The remaining accounts relate to the institutions in the SAM. All factor incomes are distributed to the single private household after making allowance for depreciation of physical capital and the payment of direct (income) taxes on factor incomes. Incomes from factor sales are also the sole source of income to the household account. Three categories of expenditures by the household account are recorded; direct (income) taxes, savings and consumption. The government receives incomes from commodity taxes, production taxes and direct taxes on factor and household incomes, and uses that income to pay for consumption and for savings. In the basic form of the database government savings are essentially zero for all regions; this

stems from the reduced form representation of intra institutional transactions provided by the GTAP database (see McDonald and Thierfelder, 2004b).[3] There are therefore five sources of savings in each region: depreciation, household/private savings, government savings, balances on trade in margin services and balances on trade in commodities, but only a single expenditure activity – investment (commodity) demand.

As should be apparent from the description of the SAM for a representative region the database is strong on inter regional transactions but relatively parsimonious on intra regional transactions.

DATABASE DIMENSIONS

The dimensions of the SAM are determined by the numbers of accounts within each aggregate group identified in Table 1, while the actual numbers of accounts in each group of accounts are defined for version 5.4 and 6.0 of the GTAP database in Table 2. Given the large number of accounts in the SAMs for each region and the relatively large number of regions the total number of cells in the global SAM is very large, although only slightly over 10 percent of the cells actually contain non zero entries; nevertheless this still means that the GTAP database contains some 4 million transaction values, which implies that there are some 8 million possible prices and quantities that can be deduced from the database. Even allowing for the implications of adopting the law of one price for transactions in the row of a each region's SAM and for other ways of reducing the numbers of independent prices and quantities that need to be estimated in a modelling environment,` it is clear that the use of the GTAP database without aggregation is likely to generate extremely large models (in terms of the number of equations/variables). Consequently, except in exceptional circumstances all CGE models that use the GTAP data operate with aggregations of the database.

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[3]   McDonald and Sonmez (2004) demonstrate a simple way to overcome some aspects of this limitation of the database.

Table 2   **Dimensions of the Global Social Accounting Matrix**

Account Groups	Sets	Total Number of Accounts	
		GTAP 5.4	**GTAP 6.0**
Commodities	c	57	57
Activities	a	57	57
Factors	f	5	5
Taxes	$(2*r)+(1*f)+3$	164	182
Other Domestic Institutions	3	3	3
Margins	$3*r$	234	261
Trade	r	78	87
	Total	598	652
Total Number of Cells in the Global SAM		27,893,112	36,984,048

3   OVERVIEW OF THE MODEL

BEHAVIOURAL RELATIONSHIPS

The within regional behavioural relationships are simple in this variant of the model; it is easy to make them more complex but the focus in this variant of the model is upon international trade relationships. The activities are assumed to maximise profits using technology characterised by Constant Elasticity of Substitution (CES) production functions between primary inputs and Leontief technology between aggregate primary inputs and intermediate inputs. The household maximises utility subject to preferences represented by a Cobb-Douglas utility function, having first paid income taxes and having saved a fixed proportion of after tax income.[4]

The Armington assumption is used for trade. Domestic output is distributed between the domestic market and exports according to a two-stage Constant Elasticity of Transformation (CET) function. In the first stage a domestic producer allocates output to the domestic or export market according to the relative prices for the commodity on the domestic market and the composite export commodity, where the composite export commodity is a CET aggregate

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[4]   A version of this model with a Linear Expenditure System is also available.

of the exports to different regions – the distribution of the exports between regions being determined by the relative export prices to those regions. Consequently domestic producers are responsive to prices in the different markets – the domestic market and all other regions in the model – and adjust their volumes of sales according relative prices. Domestic demand is satisfied by composite commodities that are formed from domestic production sold domestically and composite imports. This process is modeled by a two-stage CES function. At the bottom stage a composite import commodity is a CES aggregate of imports from different regions with the quantities imported from different regions being responsive to relative prices. The top stage defines a composite consumption commodity as a CES aggregate of a domestic commodity and a composite import commodity with the mix being determined by the relative prices. Hence the optimal ratios of imports to domestic commodities and exports to domestic commodities are determined by first order conditions based on relative prices. The price and quantity systems are described in greater detail below.

All commodity and activity taxes are expressed as simple *ad valorem* tax rates, while income taxes are defined as a fixed proportion of household income. Import duties and export taxes apply to imports and exports, while sales taxes are applied to all domestic absorption, i.e., imports are subject to sequential import duties and sales taxes. Production taxes are levied on the value of output by each activity. Income taxes are taken out of household income and then the households are assumed to save a proportion of disposable income. This proportion is either fixed or variable according to the closure rule chosen for the capital account.

Table 2 **Behavioural Relationships for a Global CGE Model**

	Commodities	Activities	Factors	Households	Government	Capital	Margins	Rest of World	Prices
Commodities	0	Leontief Input-Output Coefficients	0	Cobb-Douglas Utility Functions	Fixed Exogenously	Fixed Shares of Savings	Two-Stage CET Functions	Two-Stage CET Functions	Consumer Commodity Price
Activities	Total Supply from Domestic Production	0	0	0	0	0	0	0	Activity Prices
Factors	0	CES Production Functions	0	0	0	0	0	0	Factor Prices
Households	0	0	Fixed Shares of Factor Income	0	0	0	0	0	
Government	Ad valorem tax rates	Ad valorem tax rates	0	Average tax rates	0	0	0	0	
Capital	0	0	Shares of Factor Incomes	Shares of household income	Government Savings (Residual)	0	Current Account 'Deficit' on Margins Trade	Current Account 'Deficit	
Margins	Fixed Technical Coefficients	0	0	0	0	0	0	0	
Rest of World	Two-Stage CES Functions	0	0	0	0	0	0	0	
Prices	Producer Prices Domestic and World Prices for Imports	Value Added Prices							

Table 3 **Transactions Relationships for a for a Global CGE Model**

	Commodities	Activities	Factors	Households	Government	Capital	Margins	RoW
COMMODITIES	0	$\left(PQD_c * QINTD_c\right.$	0	$\left(PQD_c * QCD_c\right)$	$\left(PQD_c * QGD_c\right)$	$\left(PQD_c * QINVD_c\right)$		$\left(\begin{array}{c} PWE_{c,w} * QER_{c,w} \\ * ER \end{array}\right.$
Activities	$\left(PDS_c * QDS_c\right)$	0	0	0	0	0	0	0
Factors	0	$\left(WF_f * FD_{f,a}\right)$	0	0	0	0	0	
Households	0	0	$\sum_f\left(\begin{array}{c} hovash_f \\ *YF_f \end{array}\right)$	0	0	0	0	
Government	$\left(\begin{array}{c} tm_{w,c} * PWM_{w,c} \\ * QMR_{w,c} * ER \end{array}\right)$ $\left(\begin{array}{c} te_{w,c} * PWE_{w,c} \\ * QER_{w,c} * ER \end{array}\right)$ $\left(ts_c * PQS_c * QQ_c\right)$	$\left(tx_a * PX_a * QX_a\right)$		$\left(ty * YH\right)$	0	0	0	
Capital	0	0	0	$\left(kaphosh * YH\right)$	$\left(YG - EG\right)$	0		$\left(KAPREG * ER\right)$
Margins		0	0	0	0	0	0	0

Rest of World	$\begin{pmatrix} PWMFOB_{w,c} \\ *QMR_{w,c} * ER \end{pmatrix}$	0	0	0	0	0	0	0
Total	$(PQD_c * QQ_c)$	$(PX_a * QX_a)$	YF_f	YH	YG	$INVEST$		0

Government expenditure consists of commodity (final) demand, which is assumed to be fixed in real terms. Hence government saving, or the internal balance, is defined as a residual. However, the closure rules for the government account allow for various permutations. In the base case it is assumed that the tax rates and volume of government demand are fixed and government savings are calculated as a residual. However, the tax rates can all be scaled using the tax specific scaling factors; hence for instance the value of government savings can be fixed and one of the tax scalars can be made variable thereby producing an estimate of the constrained optimal tax rate. If the analyst wishes to change the relative tax rates across commodities (for import duties, export taxes and sales taxes) or across activities (for production taxes) then the respective tax rate parameters can be altered via a second adjuster. Equally the volume of government consumption can be changed by adjusting the closure rule with respect the scaling adjuster attached to the volumes of government consumption. The pattern of government expenditure is altered by changing the parameter that controls the pattern of government expenditure (*comgovconst*).

Total savings come from the households, enterprises, the internal balance on the government account and the external balance on the trade account. The external balance is defined as the difference between the value of total exports and total imports, converted into domestic currency units using the exchange rate. In the base model it is assumed that the exchange rate is fixed and hence that the external balance is variable. Alternatively the exchange rate can be made variable and the external balance can be set at a sustainable level of deficit/surplus. Expenditure by the capital account consists solely of commodity demand for investment. In the base solution it is assumed that the volume of investment adjusts so that total expenditure on investment is equal to total savings, i.e., the closure rule presumes that savings drive investment expenditures. The pattern of investment volumes is fixed, and hence the volume of each commodity changes equiproportionately according to the volume of savings. It is possible to fix the volume of real investment and then allow the savings rate by households to vary to maintain balance in the capital account, and it is possible to change the patterns of investment by changing the investment parameters (*invdconst*).

<u>PRICE AND QUANTITY SYSTEMS FOR A REPRESENTATIVE REGION</u>
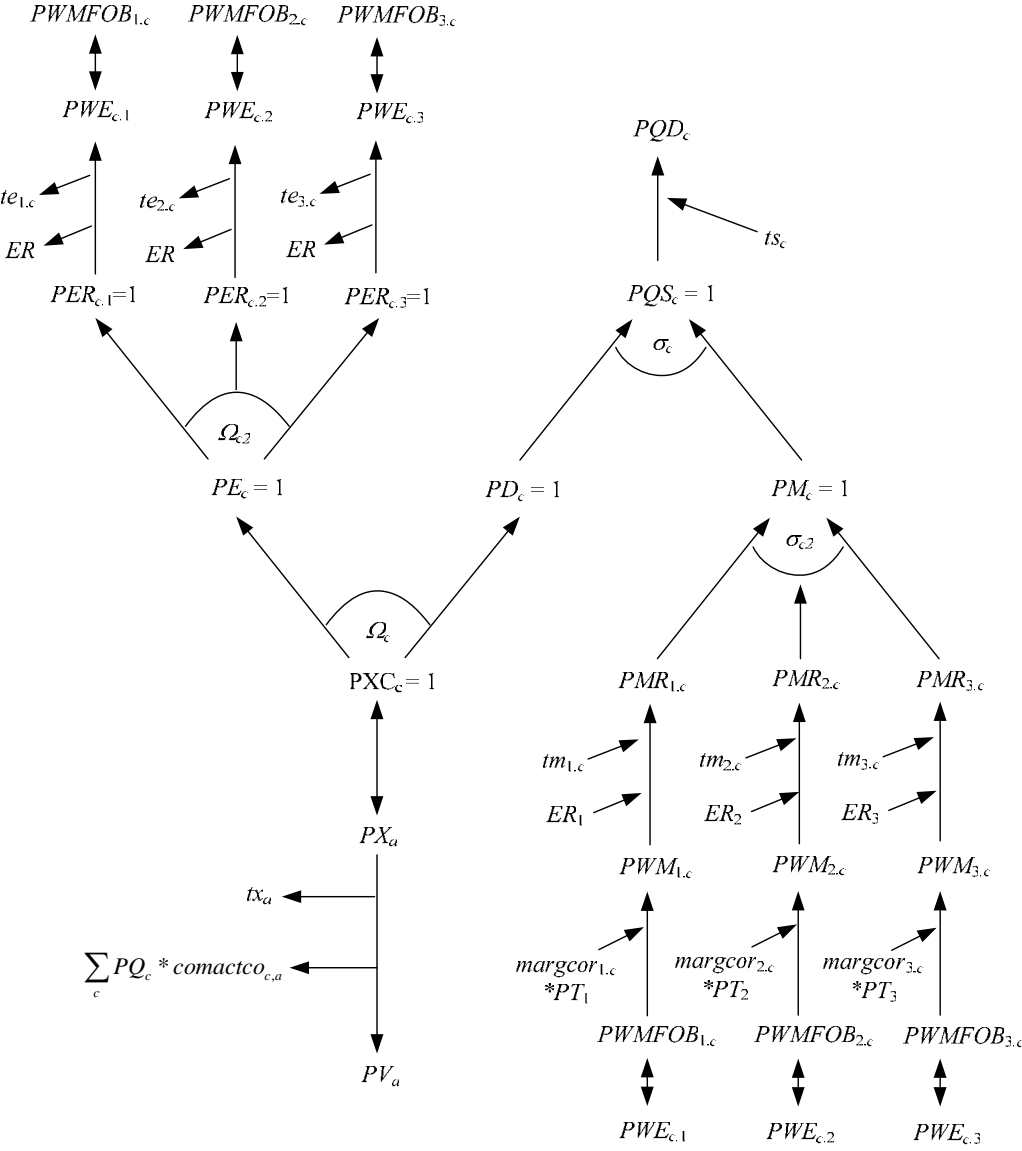
Price System

The price system is built up using the principle that the components of the 'price definitions' for each region are the entries in the columns of the SAM. Hence there are a series of explicit accounting identities that define the relationships between the prices and thereby determine the processes used to calibrate the tax rates for the base solution. However, the model is set up using a series of linear homogeneous relationships and hence is only defined in terms of relative prices. Consequently as part of the calibration process it is necessary set some of the prices equal to one (or any other number that suits the modeler) – this model adopts the convention that prices are normalised at the level of the CES and CET aggregator functions for *PXC* and *PQS*. The price system for a typical region in a 3 region global model is illustrated by Figure 1 – note that this representation abstracts from the Globe region.

The relationships between the various prices in the model are illustrated in Figure 1. The domestic consumer prices (*PQD*) are determined by the domestic prices of the domestically supplied commodities (*PD*) and the domestic prices of the composite imports (*PM*), and by the sales taxes (*ts*) that are levied on all domestic demand. The prices of the composite imports are determined as aggregates of the domestic prices paid for imports from all those regions that supply imports to this economy (*PMR*) under the maintained assumption that imports are differentiated by their source region. These region specific import prices are expressed in terms of the domestic currency units after paying for trade and transport services and any import duties. Thus a destination region is assumed to purchase a commodity in a source economy where the price is defined in the source economies currency units and is valued free on board (fob), i.e., *PWMFOB*. The carriage insurance and freight (cif) price (PWM) is then defined as the fob price plus trade and transport margin services (*margcor*) times the unit price of margin services (*PT*). The cif prices are related to the domestic price of imports by the addition of any import duties (*tm*) and then converted into domestic currency units using the nominal exchange rate (*ER*).

The prices for commodities by activities (*PXC*) are determined by the domestic prices (*PD*) and the composite export prices (*PE*). The composite export prices are a CET aggregate of the export prices received by the source economy for exports to specific destinations (*PER*), whereas the prices paid by the destination regions are net of export taxes (*te*) and are expressed in the currency units of the model's reference region by use of the nominal

exchange (*PWE*). Notice how the export prices by region of destination (*PER*) are all normalised on 1, but the seeming counterpart of normalising import prices by source region (PMR) are not normalised on 1. The link between the regions is therefore embedded in the identification of the quantities exchanged rather than the normalised prices and is a natural consequence of the normalisation process.

Figure 1 **Price System for a Typical Region**

The price system also contains a series of equilibrium identities. Namely the fob export price (PWE) for region *x* on its exports to region *y* must be identical to the fob import price (PWMFOB) paid by region *y* on its imports from region *x*. These equilibrium identities are indicated by double headed arrows.

Finally the value added prices (*PV*) are determined by the activity prices (*PX*), the production tax rates (*tx*), the input-output coefficients (*comactco*) and the commodity prices (*PQD*). The activity prices are a one to one mapping of the commodity prices received by activities (*PXC*); this is a consequence of the supply matrix being a square diagonal matrix.

Quantity System

The quantity system for a representative region is somewhat simpler. The composite consumption commodity (*QQ*) is a mix of the domestically produced commodity (*QD*) and the composite import commodity (*QM*), where the domestic and imported commodities are imperfect substitutes. The composite import commodity is also an aggregate of the commodity imported from different regions (*QMR*), which the equilibrium conditions requires are identical to the quantities exported by other regions to the representative region (*QER*). The composite consumption commodity is then allocated between domestic intermediate demands (*QINTD*), private consumption demand (*QCD*), government demand (*QGD*) and investment demand (*QINVD*).

Figure 2   Quantity System for a Typical Region
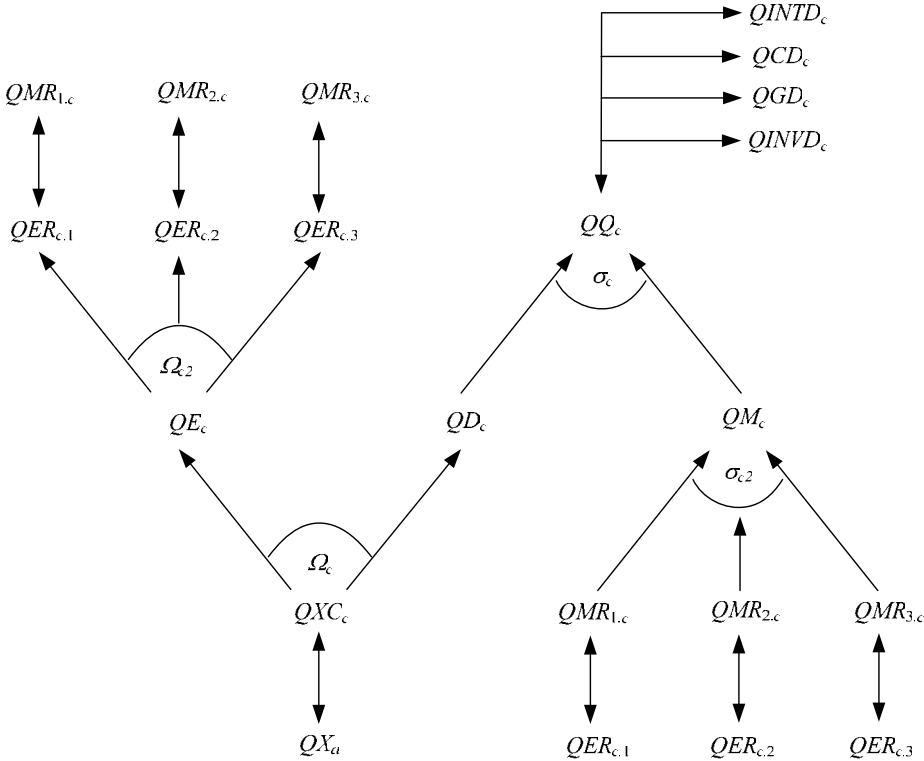
On the output side, domestic output by activity (*QX*) is identical to domestic commodity output (*QXC*). Domestic commodity is then allocated between the domestic market (*QD*) and

a composite export commodity (*QE*) under the maintained assumption of imperfect transformation, and similar the composite export commodity is allocated between the different destination regions (*QER*) under the maintain assumption of imperfect transformation.

THE GLOBE REGION

An important feature of the model is the use of the concept of a region known as Globe. While the GTAP database contains complete bilateral information relating to the trade in commodities, i.e., in all cases transactions are identified according to their region of origin and their region of destination, this is not the case for trade in margins services associated with the transportation of commodities. Rather the GTAP databases identifies the demand, in value terms, for margin services associated with imports by all regions from all other regions but does not identify the region that supplies the margin services associated with any specific transaction. Consequently the data for the demand side for margin services is relatively detailed but the supply side is not. Indeed the only supply side information is the total value of exports of margin services by each region. The Globe construct allows the model to get around this shortage of information, while simultaneously providing a general method for dealing with any other transactions data where full bilateral information is missing.

The price system for the Globe region is illustrated in Figure 3. On the import side Globe operates like all other regions. The commodities used in trade and transport services are assumed to be differentiated by source and aggregated using a CES and can *potentially* incur trade and transport margins (*margcor*) and face tariffs (*tm*); in fact the database does not include any transport margins or tariff data for margin services in relation to the destination region, although they can, and do, incur export taxes levied by the exporting region.

The export side is slightly different. In effect the Globe region is operating as a method for pooling differentiated commodities used in trade and transport services and the only differences in the use of trade and transport services associated with any specific import are the quantities of each type of trade service used and the mix of types of trade services. Underlying this is the implicit assumption that each type of trade service is homogenous, and should therefore be sold at the same price. Hence the export price system for Globe needs to be arranged so that Globe exports at a single price, i.e., there should be a infinite elasticity of substitution between each type of trade service exported irrespective of its destination region.

Therefore the average export price (*PE*) should equal the price paid by each destination region (*PER*) which should equal the export price in world currency units (*PWE*) and will be common across all destinations (*PT*).

**Figure 3** **Price System for the Globe Region**
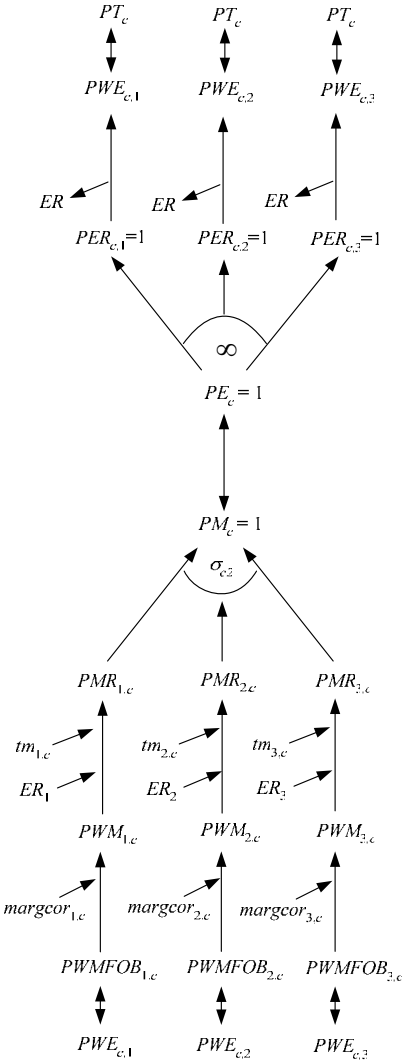
The linked quantity system contains the same asymmetry in the treatment of imports and exports by Globe, see Figure 4. The imports of trade and transport commodities are assumed to be differentiated by region of origin, hence the elasticity of substitution is greater than zero but less than infinity, while the exports of trade and transport commodities are assumed to be homogenous and hence the elasticities of transformation are infinite.

One consequence of using a Globe region for trade and transport services is that Globe runs trade balances with all other regions. These trade balances relate to the differences in the values of trade and transport commodities imported from Globe and the value of trade and

transport commodities exported to Globe; however the sum of Globe's trade balances with other regions must be zero since Globe is a artificial construct rather than a real region. But the demand for trade and transport services by any region is determined by technology, i.e., the coefficients *margcor*, and the volume of imports demanded by the destination region. This means that the price of trade and transport commodities only have an indirect effect upon their demand – the only place these prices enter into the import decision as a variable is as a partial determinant of the difference between the fob and cif valuations of other imported commodities. Consequently the primary market clearing mechanism for the Globe region comes through the quantity of trade and transport commodities it chooses to import.

Figure 4   **Quantity System for the Globe Region**
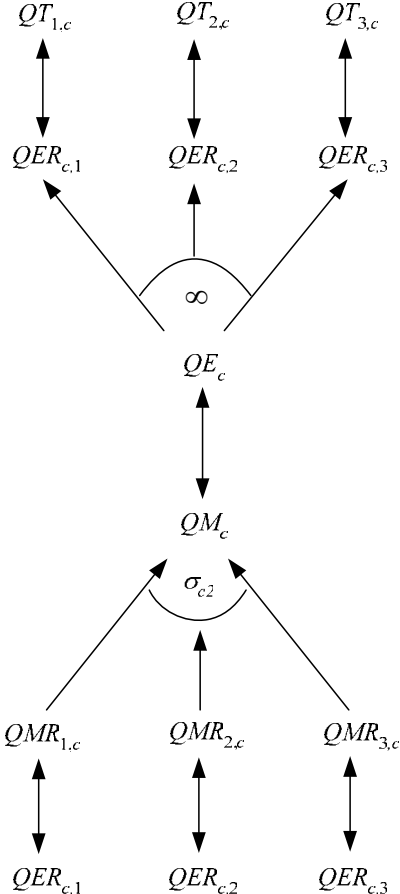
The Globe concept has other potential uses in the model. All transactions between regions for which there is an absence of full bilateral information can be routed through the Globe region. While this is not a 'first best' solution, it does provide a 'second best' method by which augmented versions of the GTAP database can be used to enrich the analyses of international trade in a global model prior to availability of full bilateral transactions data.

4. FORMAL DESCRIPTION OF THE MODEL

This formal description of the model proceeds in four stages with three of them in this section and the fourth, relating to model closure rules, being detailed in the next section. For this section the description begins with identification of the sets used in the model, this is followed by details of each equation (block) in the model and ends with a table that summarises all the equations and identifies the associated variables, the counts for equations and variables and identifies whether the equation is implemented or not for the Globe region.

MODEL SETS

Rather than writing out each and every equation in detail it is useful to start by defining a series of sets; thereafter if a behavioural relationship applies to all members of a set an equation only needs to be specified once. The natural choice for this model is a set for all the transactions by each region (*sac*) plus a series of sets that group commodities, activities, factors, import duties, export taxes, trade margins, trade and finally some individual accounts relating to domestic institutions. The outer set for any region is defined as

$$sac = \{c, a, f, hous, tmr, ter, tff, prodtax, saltax, dirtax, govt, kap, owatpmarg, w, total\}$$

and the following are the basic sets for each region in this model

$$c(sac) = \{\text{commodities}\}$$
$$a(sac) = \{\text{activities}\}$$
$$f(sac) = \{\text{factors}\}$$
$$tmr(sac) = \{\text{import duties}\}$$
$$ter(sac) = \{\text{export taxes}\}$$
$$tmr(sac) = \{\text{factort taxes}\}$$
$$owatpmarg(sac) = \{\text{trade and transport margins}\}$$
$$w(sac) = \{\text{rest of the world - trade}\}$$

Various subsets of *c* are declared and then assigned on the basis of certain characteristics of the data set used to calibrate the specific implementation of the model, so-called dynamic sets. These subsets are

$$ct(c, r) = \{\text{trade margin commodities}\}$$

$$ctn(c, r) = \{\text{non-trade margin commodities}\}$$

$$ce(c, r) = \{\text{export commodities}\}$$

$$cen(c, r) = \{\text{non-export commodities}\}$$

$$cer(c, r, w) = \{\text{export commodities by region}\}$$

$$cern(c, r, w) = \{\text{non-export commodities by region}\}$$

$$cm(c, r) = \{\text{imported commodities}\}$$

$$cmn(c, r) = \{\text{non-imported commodities}\}$$

$$cmr(c, r, w) = \{\text{imported commodities by region}\}$$

$$cmrn(c, r, w) = \{\text{non-imported commodities by region}\}$$

$$cx(c, r) = \{\text{commodities produced domestically}\}$$

$$cxn(c, r) = \{\text{commodities NOT produced domestically AND imported}\}$$

$$cd(c, r) = \{\text{commodities produced AND demanded domestically}\}$$

$$cdn(c, r) = \{\text{commodities NOT produced AND demanded domestically}\}$$

$$cintd(c, r) = \{\text{commodities WITH intermediate demand by region}\}$$

$$cintdn(c, r) = \{\text{commodities WITHOUT intermediate demand by region}\}$$

It is also necessary to define a set of region, *r*, for which there are two subsets

$$r2(r) = \{\text{all regions excluding Globe}\}$$

$$ref(r) = \{\text{reference regions for global numeraire}\}.$$

A macro SAM that can be used to check various aspects of model calibration and operation is very useful. This needs another set

$$ss = \{commdty, activity, valuad, hholds, tmtax, tetax, govtn, kapital, margs, world, totals\}$$

Reserved Names

The model uses a number of names that are reserved. The majorities of these reserved names relate to taxes and are reserved to ease the modeling of tax instruments; these are

DIRTAX	Direct Taxes
SALTAX	Sales Taxes
PRODTAX	Production Taxes
FACTAX	Factor Taxes

The other reserved name is for the capital/savings account. The reserved name is kap and this account handles all investment expenditures and savings.

Conventions

The equations for the model are set out in ten 'blocks'; which group the equations under the following headings 'exchange rates', 'trade' – with sub blocks for 'exports' and 'imports', 'commodity prices', 'numéraire', 'production', 'factors', 'household', 'government' – with sub blocks for 'taxes' and 'expenditure', 'kapital' (savings and investment) and 'market clearing' – with various sub blocks for different dimensions of model closure. This grouping of equations is for ease of reading of the model rather than being a requirement of the model.

A series of conventions are adopted for the naming of variables and parameters. These conventions are not a requirement of the modeling language; rather they are designed to ease reading of the model.

- All VARIABLES are in upper case.
- The standard prefixes for variable names are: P for price variables, Q for quantity variables, W for factor prices, F for factor quantities, E for expenditure variables, Y for income variables, and V for value variables
- All variables have a matching parameter that identifies the value of the variable in the base period. These parameters are in upper case and carry a '0' suffix, and are used to initialise variables.
- A series of variables are declared that allow for the equiproportionate adjustment of groups of parameters. These variables are named using the convention ***ADJ*, where ** is the parameter series they adjust.
- All parameters are in lower case, except those used to initialise variables.
- Names for parameters are derived using account abbreviations with the row account first and the column account second, e.g., actcom** is a parameter referring to the activity:commodity (supply or make) sub-matrix;
- Parameter names have a two or five character suffix which distinguishes their definition, e.g., **sh is a share parameter, **av is an average and **const is a constant parameter;

EQUATIONS FOR THE MODEL

The model equations are reported and described below and then they are summarised in Table4.

Exports Block Equations

The domestic prices of commodity exports, *c*, by destination, *w*, and source, *r*, region (*PER*) are defined as the product of world prices of exports (*PWE*) – also defined by commodity and destination and source region, the source region's exchange rate (*ER*) and one minus the export subsidy rate[5] (*te*) multiplied by a region specific export subsidy rate adjustment variable (*TEADJ*).

$$PER_{c,r,w} = PWE_{c,r,w} * ER_r * \left(1 - \left(TEADJ_r * te_{c,r,w}\right)\right) \qquad \forall c \in cer \qquad \text{(X1)}$$

The possibility of non-traded commodities means that the equations for the domestic prices of exports (and imports) are only implemented for those commodities that are traded; this requires the use of a dynamic set, *cer*, which is defined by those commodities that are exported in the base data. Also notice that the world prices of exports (*PWE*) are defined as variables; in a global model the small country trade assumption is not valid since, by definition, world prices are endogenous and therefore ALL regions are treated as 'large' producers of a commodity.

The prices of the composite export commodities can then be expressed as simple volume weighted averages of the of the export prices by region,

$$PE_{c,r} * QE_{c,r} = \sum_w PER_{c,r,w} * QER_{c,r,w} \qquad \forall c \in ce, r \in r2 \qquad \text{(X2)}$$

where $PE_{c,r}$ and $QE_{c,r}$ the price and quantity of the composite export commodity *c* from region *r*, and the weights are the volume shares of exports and are variable. This comes from the fact that a CET function is liner homogenous and hence Eulers theorem can be applied. Notice however that (X2) is only implemented of the set *r2*, i.e., the region Globe is excluded. Rather the composite export price for trade margin commodities from Globe is given by

$$PER_{c,r,w} = PE_{c,r} \qquad \forall c \in ct2, r \notin r2, w \in w2 \qquad \text{(X3)}$$

---

[5]   Defining export taxes as negative subsidies means that there is symmetry between the treatment of import duties and export subsidies when coding the model in GAMS.

which indicates that it is assumed that the trade margin commodities exported by Globe are perfect substitutes for each other, i.e., the same price is paid for each trade margin commodity by ALL purchasing regions.

Domestic commodity outputs (*QXC*) are either exported (*QE*) as composite commodities or supplied to the domestic market (*QD*). The allocation of output between the domestic and export markets is determined by the output transformation functions, Constant Elasticity of Transformation (CET) functions, (X4)

$$QXC_{c,r} = at_{c,r} \left(\gamma_{c,r} * QE_{c,r}^{rhot_{c,r}} + \left(1 - \gamma_{c,r}\right) * QD_{c,r}^{rhot_{c,r}} \right)^{\frac{1}{rhot_{c,r}}}$$

$$\forall c \in \left(cd \cap ce\right), r \in r2$$

(X4)

with the optimum combinations of *QE* and *QD* determined by first-order conditions (X5)

$$\frac{QE_{c,r}}{QD_{c,r}} = \left[\frac{PE_{c,r}}{PD_{c,r}} * \frac{\left(1 - \gamma_{c,r}\right)}{\gamma_{c,r}} \right]^{\frac{1}{(rhot_{c,r}-1)}} \qquad \forall c \in \left(cd \cap ce\right), r \in r2 .$$

(X5)

However, some commodities are non-traded and therefore X4 and X5 are implemented if and only if the commodity is traded. This means that domestic commodity outputs are undefined for non-traded commodities, but by definition the quantity supplied to the domestic market is the amount produced, hence

$$QXC_{c,r} = QD_{c,r} \qquad \forall c \in \left(cd \cap cen\right), r \in r2 .$$

(X6)

Furthermore it is necessary to cover the possibility that a commodity may be produced domestically and exported but not consumed domestically, hence

$$QXC_{c,r} = QE_{c,r} \qquad \forall c \in \left(cdn \cap ce\right), r \in r2 .$$

(X7)

These quantity equations deal however only with the composite export commodities, i.e., hypothetical commodities whose roles in the model are to act as neutral intermediaries that enter into the first-order conditions that determine the optimal mix between domestic use and exports of domestic commodity production (X5). In fact the composite export commodities are themselves CET aggregates of commodity exports to different regions (*QER*), i.e.,

$$QER_{c,r,w} = QE_{c,r} * \left(\frac{PER_{c,r,w}}{PE_{c,r} * gammr_{c,r,w} * atr_{c,r}^{rhot_{c,r}^r}} \right)^{1/\left(rhot_{c,r}^r - 1\right)} \tag{X8}$$

$$\forall c \in cer, r \in r2$$

for which the corresponding first order condition is given by (X2). Note however that (X8) does not define the exports of trade margin commodities BY Globe; this is because these commodities are assumed to be perfect substitutes and therefore simple addition is adequate, i.e.,

$$QE_{c,r} = \sum_w QER_{c,r,w} \qquad \forall c \in ct, r \notin r2. \tag{X9}$$

Finally there is a need for an equilibrium conditions for trade by Globe. Since Globe is a artificial construct whose sole role in the model is to gather exports whose destinations are unknown and supply imports whose sources are unknown, and visa versa, it must always balance its trade within each period. Thus the volume exports of trade margin commodities by Globe must be exactly equal to the volume imports of trade margin commodities, i.e.,

$$QE_{c,r} = QM_{c,r} \qquad \forall c \in ct2, r \notin r2. \tag{X10}$$

Imports Block Equations

The prices of imported commodities are made up of several components. The export price in foreign currency units – valued free on board (fob) (*PWMFOB*) – plus the cost of trade and transport services, which gives the import price carriage insurance and freight (cif) paid (*PWM*), plus any import duties; all of which are then converted into domestic currency units (*PMR*). Clearly the import price values fob (*PWMFOB*) is identical to the export price valued fob (*PWE*) – this condition is imposed in the market clearing block (see below) – and hence the cif price can be defined as

$$PWM_{c,r,w} = PWMFOB_{c,r,w} + \sum_{cp \in ct} margcor_{cp,c,r,w} * PT_{cp,r} \tag{M1}$$

$$\forall c \in cmr$$

where *margcor* is the quantity of trade and transport services required to import a unit of the imported commodity and *PT* is the price of trade and transport services. Embedded in the definition of the coefficient *margcor* is the explicit assumption that transporting a commodity from a specific source to a specific destination requires the use of a specific quantity of services – the actual cost of these services can vary according to changes in the prices of the

trade and transport services or the quantity of services required to transport a particular commodity.

The domestic prices of imports from a region (*PMR*) are defined as the product of world prices of imports (*PWM*) – after payment for carriage, insurance and freight (cif) - the exchange rate (*ER*) and one plus the import tariff rate (*tm*) multiplied by a tariff rate adjustment variable (*TMADJ*)

$$PMR_{c,r,w} = PWM_{c,r,w} * ER_r * \left(1 + \left(TMADJ_r * tm_{c,r,w}\right)\right) \\ \forall c \in cmr \tag{M2}$$

The possibility of non-traded commodities means that the equations for the domestic prices of imports are only implemented for those commodities that are traded; this requires the use of a dynamic set, *cmr*, which is defined by those commodities that are imported by a region from another region in the base data. Also notice how the world prices of imports (*PWM*) are defined as variables.

The prices of the composite import commodities can then be expressed as simple volume weighted averages of the of the export prices by region,

$$PM_{c,r} * QM_{c,r} = \sum_w PMR_{c,r,w} * QMR_{c,r,w} \qquad \forall c \in cm \tag{M3}$$

where $PM_{c,r}$ and $QM_{c,r}$ the price and quantity of the composite import commodity *c* by region *r*, and the weights are the volume shares of imports and are variable. This comes from the fact that a CES function is liner homogenous and hence Eulers theorem can be applied. Notice however that (M3) is only controlled by the set *cm*, in contrast to (X2) – the composite export price – which was also controlled by the set *r2*, i.e., the region Globe was excluded. This reflects the fact that the region Globe does import commodities using the same trading assumption as other regions but only exports homogenous trade and transport services, which explains the need for the equation (X3).

However, both domestic and foreign producers can supply commodities to the domestic market. The composite (consumption) commodities are a mixture of composite imports (*QM*) and domestic demand from domestic production (*QD*). The mixtures between the domestic and import supplies are determined by the substitution functions, Constant Elasticity of Substitution (CES) functions, i.e.,

$$QQ_{c,r} = ac_{c,r} \left(\delta_{c,r} * QM_{c,r}^{-rhoc_{c,r}} + \left(1 - \delta_{c,r}\right) * QD_{c,r}^{-rhoc_{c,r}} \right)^{-\left(\frac{1}{rhoc_{c,r}}\right)}$$

$$\forall c \in \left(cx \cap cm\right), r \in r2 \tag{M4}$$

with the optimal combinations of *QM* and *QD* being determined by first-order conditions, i.e.,

$$\frac{QM_{c,r}}{QD_{c,r}} = \left[\frac{PD_{c,r}}{PM_{c,r}} * \frac{\delta_{c,r}}{\left(1 - \delta_{c,r}\right)} \right]^{\frac{1}{\left(1 + rhoc_{c,r}\right)}} \qquad \forall c \in \left(cx \cap cm\right), r \in r2. \tag{M5}$$

However, some commodities are non-traded and therefore M4 and M5 are implemented only if the commodity is traded. This leaves *QQ* undefined for non-traded commodities, but by definition the quantity demanded by the domestic market is the amount produced, hence

$$QQ_{c,r} = QD_{c,r} \qquad \forall c \in \left(cx \cap cmn\right), r \in r2. \tag{M6}$$

Furthermore, it is necessary to cover the possibility that there is no domestic production of a commodity, hence

$$QQ_{c,r} = QM_{c,r} \qquad \forall c \in \left(cxn \cap cm\right), r \in r2. \tag{M7}$$

The composite import commodities are defined as CES aggregates of the imports from different regions (*QMR*), i.e.,

$$QMR_{c,r,w} = QM_{c,r} * \left(\frac{PMR_{c,r,w} * acr_{c,r}^{rhoc_{c,r}^{r}}}{PM_{c,r} * delta_{c,r,w}^{r}} \right)^{-1/\left(rhoc_{c,r}^{r}+1\right)} \qquad \forall c \in cmr \tag{M8}$$

where the first order conditions come from the price definition terms for composite imports, *PM* (M2) and are only implemented for those cases where there were import transactions in the base period – this is controlled by the set *cmr*. However also associated with any imported commodity is a specific quantity of trade and transport services. These services are assumed to be required in fixed quantities per unit of import by a specific region from another specific region, i.e.,

$$QT_{c,r,w} = \sum_{cp} \left(QMR_{cp,r,w} * margcor_{c,cp,r,w} \right) \qquad \forall c \in ct2, r \in r2 \tag{M9}$$

where the *margcor* are the trade and transport coefficients associated with a unit (quantity) import by region *r* from region *w*. This is only implemented for trade and transport commodities (*ct2*) and for regions that 'actually' import goods (*r2*).

Commodity Price Block Equations

The composite price equations (CP1, CP2 and CP3) are derived from the first order conditions for tangencies to consumption and production possibility frontiers. By exploiting Euler's theorem for linearly homogeneous functions the composite prices can be expressed as expenditure identities rather than dual price equations for export transformation and import aggregation, such that *PQS* is the weighted average of the producer price of a commodity, when *PD* is the producer price of domestically produced commodities and *PM* the domestic price of the composite imported commodity, i.e.,

$$PQS_{c,r} = \left(PD_{c,r} * QD_{c,r}\right) + \left(PM_{c,r} * QM_{c,r}\right) \qquad \forall c \in \left(cd \cup cm\right), r \in r2 . \quad \text{(CP1)}$$

where *QD* the quantity of the domestic commodity demanded by domestic consumers, *QM* the quantity of composite imports and *QQ* the quantity of the composite commodity. Notice how the commodity quantities are the weights. This composite commodity price (CP1) does not include sales taxes, which create price wedges between the purchaser price of a commodity (*PQD*) and the producer prices (*PQS*). Hence the purchaser price is defined as the producer price plus the sales taxes (CP2), i.e.,

$$PQD_{c,r} = PQS_{c,r} * \left(1 + \left(TSADJ_r * ts_{c,r}\right)\right) \qquad \forall c \in \left(cd \cup cm\right), r \in r2 . \quad \text{(CP2)}$$

This formulation means that the sales taxes are levied on all sales on the domestic market, irrespective of the origin of the commodity concerned.

The composite output price for a commodity is also derived by exploiting Euler's theorem for linearly homogeneous functions, and is given by

$$PXC_{c,r} = \frac{\left(PD_{c,r} * QD_{c,r}\right) + \left(PE_{c \in ce,r} * QE_{c \in ce,r}\right)}{QXC_c} . \quad \text{(CP3)}$$
$$\forall c \in cx, r \in r2$$

where *PD* is the domestic producer price for the output of commodities supplied to the domestic market, *QD* is the supply of output to the domestic market, *QE* is the quantity exported by activities, *PXC* is the composite output price by commodity and *QXC* is the quantity of domestic production by commodity.

Numéraire Price Block

It is also desirable to define a price numéraire for each region; for this model two alternative numéraire are defined so as to allow the modeler some discretion as to the choice of numéraire. The consumer price indices (*CPI*) are defined as base weighted sum of the commodity prices, where the weights are the value shares of each commodity in final demand (*comtotsh$_c$*), i.e.,

$$CPI_r = \sum_c comtotsh_{c,r} * PQ_{c,r} \qquad \forall r \in r2 . \tag{N1}$$

The domestic producer price indices (*PPI*) are defined as the weighted sums of the commodity prices received by producers on the domestic market, where the weights are the value shares of each commodity supplied by domestic producers to the domestic market (*vddtotsh$_c$*), i.e.,

$$PPI_r = \sum_c vddtotsh_{c,r} * PD_{c,r} \qquad \forall r \in r2 . \tag{N2}$$

This provides a convenient alternative price normalisation term; if the exchange rate is also fixed it serves to fix the real exchange rate.

Notice how both price indices are controlled to be implemented only for those regions that have consumption and production activities. Hence the Globe does not have its own price indices, rather the price indices for Globe are those of the reference region in the model.

Production Block Equations

The output price by activity (*PX*) is defined by the share of commodity outputs produced by each activity, as

$$PX_{a,r} = \sum_c actcomactsh_{a,c,r} * PXC_{c,r} \quad \forall r \in r2 \tag{P1}$$

where, for this case, the weights (*actcomactsh*) are equal to one where the commodities and activities match and zero otherwise, i.e., there is a one to one mapping between the commodity and activity accounts. The weights are derived from the information in the supply or make matrix.

The presence of intermediate inputs and production taxes in this system requires the definition of the value added price (*PV*). This is defined as the activity price (*PX*) less

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payments for intermediate inputs and production taxes per unit of output (*tx*) multiplied by an indirect tax rate adjustment variable (*TXADJ*). The assumption of fixed proportions in the use of intermediate inputs, i.e., Leontief style input-output coefficients (*comactco*), means that the payments for intermediate inputs are the weighted sums of the intermediate input coefficients where the weights are the consumer prices of the composite commodities, i.e.,

$$PV_{a,r} = \left(PX_{a,r} * \left(1 - \left(TXADJ_r * tx_{a,r} \right) \right) \right) - \left(\sum_c PQ_{c,r} * comactco_{c,a,r} \right).$$

$$\forall r \in r2$$

(P2)

The production sub-block consists of the production function (P3), a mapping of activity outputs (*QX_a*) into commodity supplies (P6) and first order conditions for profit maximization (P4). The specification for production uses CES production functions, which allows for elasticities of substitution other than unity. Again it is an aggregation function over the all factors that are demanded by each activity (*FD_{f,a}*), where

$$QX_{a,r} = adces_{a,r} * \left[\sum_f \delta^x_{f,a,r} * FD^{-\rho^x_{a,r}}_{f,a,r} \right]^{-1/\rho^x_{a,r}} \quad \forall r \in r2$$

(P3)

with efficiency parameters (*adces_{a,r}*) and the factor shares ($\delta^x_{f,a,r}$) calibrated from the data and the elasticities of substitution, from which the substitution parameters are derived ($\rho^x_{a,r}$), exogenously imposed. The associated first-order conditions for optimal factor combinations are derived from equalities between the wage rates for each factor in each activity and the values of the marginal products of those factors in each activity, i.e.,

$$WF_{f,r} * WFDIST_{f,a,r}$$

$$= PV_{a,r} * adces_{a,r} * \left[\sum_f \delta^x_{f,a,r} * FD^{-\rho^x_{a,r}}_{f,a,r} \right]^{\left(\left(\frac{-1}{\rho^x_{a,r}} \right) - 1 \right)} * \delta^x_{f,a,r} * FD^{\left(-\rho^x_{a,r} - 1 \right)}_{f,a,r}.$$

$$\forall r \in r2, \delta^x_{f,a,r}$$

(P4)

Since production uses intermediate inputs it is also necessary to specify the demand for intermediate inputs (*QINTD*). This is done from the perspective of commodity demands, i.e., it is summed over activities to produce the demand for intermediate inputs by commodity rather than by activity

$$QINTD_{c,r} = \sum_a comactco_{c,a,r} * QX_{a,r} \quad \forall r \in r2, c \text{ int } d \text{ ???}$$

(P5)

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This is linked to the market clearing equation ??? below. Finally it is necessary to define the relationship between activity and commodity outputs, which is the counterpart to the price equation linking commodity and activity prices (P1). This is defined as a simple linear relationship whereby the commodity output is defined as the sum of the quantities of each commodity produced by each activity, i.e.,

$$QXC_{c,r} = \sum_a actcomactsh_{a,c,r} * QX_{a,r} \qquad \forall r \in r2 . \tag{P6}$$

Factor Block Equations

The total income received by each factor account (YF_f) is defined as the summation of the earnings of that factor across all activities (F1),

$$YF_{f,r} = \sum_a WF_{f,r} * WFDIST_{f,a,r} * FD_{f,a,r} \qquad \forall r \in r2 . \tag{F1}$$

Only a proportion of total factor income is available for distribution to the domestic institutional accounts. First allowance must be made for depreciation, which it is assumed takes place at fixed rates ($deprec_{f,r}$) relative to factor incomes and the payment of factor income taxes ($tyf_{f,r}$) that are assumed to be simple average ad valorem rates but with the option of an adjustment factor (*TYFADJ*), i.e.,

$$YFDIST_{f,r} = \left(YF_{f,r} - \left(deprec_{f,r} * YF_{f,r}\right)\right) * \left(1 - \left(TYFADJ_r * tyf_{f,r}\right)\right) \\ \forall r \in r2 \tag{F2}$$

Although implemented over all factors, this equation is only relevant in this model for income to the factor capital.

Household Block Equations

Households acquire income from only one source in this model; the sale of factor services. Therefore household income (*YH*) is defined as

$$YH_{h,r} = \sum_f YFDIST_{f,r} \quad \forall r \in r2 . \tag{H1}$$

Household consumption demand is derived in two stages. In the first stage (H2) household consumption expenditures (*HEXP*) are defined as household incomes after the payment of direct taxes and savings and inter household transfers, i.e.,

$$HEXP_{h,r} = \left(YH_{h,r} * \left(1 - \left(TYHADJ_r * tyh_{h,r}\right)\right)\right)$$
$$* \left(1 - \left(SADJ_r * kaphsh_{h,r}\right)\right) \quad \forall r \in r2 \tag{H2}$$

Note how the saving rates are defined as proportions of after tax incomes that are saved; this is important for the calibration of the income tax and savings parameters. The quantities of each commodity demanded by the household are then defined by the shares of household consumption expenditure (*comhoav*) divided by the consumer price of the specific commodity (H3). This is a specification for a Cobb-Douglas utility function, i.e.,

$$QCD_{c,r} = \frac{\left(\sum_h comhoav_{c,h,r} * HEXP_{h,r}\right)}{PQ_{c,r}} \quad \forall r \in r2. \tag{H3}$$

One advantage of the Cobb-Douglas specification is that it results in the changes in the values for household consumption expenditures (*HEXP*) being equal to the changes in an equivalent variation measure of household welfare.

Government Tax Block Equations

There are six tax instruments. Each is defined as a simple *ad valorem* rate dependent upon the values of imports, exports, sales or production and the levels of factor and household and income. The 'tax' rates are all declared as parameters and then for each tax instrument a scaling variable is declared to facilitate policy experiments. Import duties (*MTAX*) are defined as

$$MTAX_r = \sum_w \sum_c \left(TMADJ_r * tm_{c,r,w} * PWM_{c,r,w} * ER_r * QMR_{c,r,w}\right)$$
$$\forall r \in r2 \tag{T1}$$

where *tm* is the tariff rate and *TMADJ* the scaling variable. Export taxes (*ETAX*) are defined as

$$ETAX_r = \sum_w \sum_c \left(TEADJ_r * te_{c,r,w} * PWE_{c,r,w} * ER_r * QER_{c,r,w}\right)$$
$$\forall r \in r2 \tag{T2}$$

where *te* is the export duty rate and *TEADJ* the scaling variable. Sales taxes (*STAX*) are defined as

$$STAX_r = \sum_c \left(\begin{matrix} TSADJ_r * ts_{c,r} * PQ_{c,r} \\ *\left(QINTD_{c,r} + QCD_{c,r} + QGD_{c,r} + QINVD_{c,r}\right) \end{matrix} \right) \quad \forall r \in r2 \qquad \text{(T3)}$$

where *ts* is the sales tax rate and *TSADJ* the scaling variable. Indirect/production taxes (*ITAX*) are defined as

$$ITAX_r = \sum_a \left(TXADJ_r * tx_{a,r} * PX_{a,r} * QX_{a,r}\right) \quad \forall r \in r2 \qquad \text{(T4)}$$

where *tx* is the indirect tax rate and *TXADJ* the scaling variable. Factor income taxes (FTAX) are defined as

$$FTAX_r = \sum_f \left(TYFADJ_r * tyf_{f,r} * \left(YF_{f,r} - \left(deprec_{f,r} * YF_{f,r}\right)\right)\right)$$
$$\forall r \in r2 \qquad \text{(T5)}$$

where *tyf* is the factor income tax rate and *TYFADJ* the scaling variable. Household income taxes (*DTAX*) are defined as

$$HTAX_r = \sum_h \left(TYHADJ_r * tyh_{h,r} * YH_{h,r}\right) \qquad \forall r \in r2 \qquad \text{(T)}$$

where *tyh* is the household income tax rate and *TYHADJ* the scaling variable.

Government Block Equations

Government income (*YG*) is defined as the sum of government tax revenues (G1), i.e.,

$$YG_r = MTAX_r + ETAX_r + STAX_r + ITAX_r + FTAX_r + HTAX_r$$
$$\forall r \in r2 \qquad . \qquad \text{(G1)}$$

The tax revenues are treated as expenditures by the accounts paying the taxes and hence are defined in the tax block. Although this approach adds equations it has the arguable advantage of being more transparent and easier to modify.

Government demand for commodities (G2) is assumed fixed in real terms, i.e., the volume is fixed, but can be scaled or allowed to vary using an adjustment factor (*QGDADJ*). The precise specification depends upon the choice of closure rule (see below).

$$QGD_{c,r} = comgovconst_{c,r} * QGDADJ_r \qquad \forall r \in r2 . \qquad \text{(G2)}$$

Thereafter Government consumption expenditure (*EG*) is defined as the sum of commodity consumption

$$EG_r = \sum_c PQ_{c,r} * QGD_{c,r} \qquad \forall r \in r2 . \tag{G3}$$

Kapital Account Block Equations

Income to the capital (savings and investment) account comes from household savings, depreciation allowances, government savings (*KAPGOV*) and the surplus on the capital account of the balance of payments (*KAPWOR*) (K1). Hence total savings are defined as

$$
\begin{aligned}
TOTSAV_r = {}& \left(\sum_h \left(YH_{h,r} * \left(1 - \left(TYHADJ_r * tyh_{h,r} \right) \right) \right) * \left(SADJ_r * kaphsh_{h,r} \right) \right) \\
& + \sum_f deprec_{f,r} * YF_{f,r} \\
& + KAPGOV_r + \left(KAPWOR_r * ER_r \right) \qquad \forall r \in r2
\end{aligned}
\tag{K1}
$$

In this model the household is assumed to save fixed proportions (*kaphsh*) of their income after tax. Both the household savings and income tax rates are multiplied by adjustment variables (*SADJ* and *TYHADJ*). The savings rate adjustment variable means savings rates can adjust to achieve an exogenously defined level of total savings if an investment driven closure rule is assumed. It may be helpful to assign (K1) simultaneously with (H2) to ensure correct calibration of the income tax and saving rate parameters. Government savings are calculated as residual (see the *KAPGOV* equations below): note that the surplus on the capital account (*KAPWOR*) is defined in terms of the foreign currency and therefore the exchange rate appears in this equation (this is a matter of preference).

Investment demand is modeled in a similar way to government demand. Demand for commodities (K2) used in investment is assumed to be in fixed volumes (*invconst*) multiplied by an investment-scaling variable (*IADJ*) that can accommodate changes in the exogenously determined level of investment and/or changes in the availability of funds for investment, i.e.,

$$QINVD_{c,r} = IADJ_r * invconst_{c,r} \qquad \forall r \in r2 . \tag{K2}$$

The second stage (K3) captures the price effect by identifying the total value of investment (*INVEST*), i.e.,

$$INVEST_r = \sum_c \left(PQ_{c,r} * QINVD_{c,r} \right) \qquad \forall r \in r2 . \tag{K3}$$

Market Clearing Block Equations

The market clearing, or equilibrium, conditions are straightforward. Factor supplies must equal factor demands (MC1)

$$FS_{f,r} = \sum_a FD_{f,a,r} \qquad \forall r \in r2 \qquad\qquad (MC1)$$

and (composite) commodity supplies must equal (composite) commodity demands (MC2)

$$QQ_{c,r} = QINTD_{c,r} + QCD_{c,r} + QGD_{c,r} + QINVD_{c,r}$$
$$\forall c \in (cd \cup cm), r \in r2 \qquad\qquad (MC2)$$

It appears that there is no equilibrium condition for the supply of domestic output to the domestic market. In fact this is achieved through the commodity output equation (P5), which could have been treated as a market clearing equation.

The government account is cleared by defining government savings (*KAPGOV*) as the difference between government income and government expenditure on consumption and transfers, hence government savings are explicitly treated as a residual, i.e.,

$$KAPGOV_r = YG_r - EG_r \qquad \forall r \in r2 . \qquad\qquad (MC3)$$

The deficit on the current account is computed in two-stages. First the bilateral trade balances (*KAPREG*) are calculated as the difference in the values of imports and exports – for convenience theses are evaluated in the currency of the reference region, i.e.,

$$KAPREG_{r,w} = \left(\sum_c PWM_{c,r,w} * QMR_{c,r,w} \right)$$
$$- \left(\sum_c PWE_{c,r,w} * QER_{c,r,w} \right) \qquad \forall r \in r2 \qquad\qquad (MC4)$$

and then the overall balance of trade (*KAPWOR*) is computed for each region, i.e.,

$$KAPWOR_{r2} = \left(\sum_w \sum_c PWM_{c,r2,w} * QMR_{c,r2,w} \right)$$
$$- \left(\sum_w \sum_c PWE_{c,r2,w} * QER_{c,r2,w} \right) \qquad \forall r \in r2 \qquad\qquad (MC5)$$

Note how Globe is excluded from the overall balance of trade condition – this is because Globe is defined such that for each set of import transactions there is a matching set of export

transactions and these are equated in both value and quantity terms. Also because (MC5) is defined in terms of the 'foreign' currency it is necessary to convert *KAPWOR* into domestic currency terms when it enters into any other equation, e.g., the total savings equation (*TOTSAV*).

The next pairs of market clearing conditions relate to trade in commodities. The first set trade consistency conditions (*TRCONP*) deal with the fob prices of imports and exports; by definition these must be identical and hence

$$PWMFOB_{c,r,w} = PWE_{c,rp,wp} \qquad \forall c \in cmr. \qquad \text{(MC6)}$$

These equations are not completely straightforward since it is necessary in their implementation to employ mappings between exporting and importing regions that require the 'switching' of labels on accounts within the equation. The second set trade consistency conditions (*TRCONQ*) deal with the quantities of imports and exports; by definition these must be identical and hence

$$QMR_{c,r,w} = QER_{c,rp,wp} \quad \forall c \in cmr \qquad \text{(MC7)}$$

again these equations are not completely straightforward since it is necessary in their implementation to employ mappings between exporting and importing regions.

The trade consistency equations do not however deal with the requirements for market clearing with respect to the trade transactions undertaken by the Globe region. These require that the total demand for each and every trade and transport service (*QT*) is exactly equal to the exports of that service by Globe, i.e.,

$$\sum_w QT_{c,r,w} = QER_{c,r,w} \qquad\qquad \forall c \in ct2, r \in r2. \qquad \text{(MC8)}$$

And second that the export price of each and every trade and transport margin service is identical irrespective of the region that is importing the service. i.e.,

$$PT_{c,r} = PWE_{c,r,w} \qquad \forall c \in ct2, r \in r2 \qquad \text{(MC9)}$$

which embodies the presumption that trade and transports services of each type are identical irrespective of who supplies or purchases them.

And finally, there are two equilibrium conditions for the capital account. First, which ensures that the values of total savings and investment in a region are equates, i.e.,

$$TOTSAV_r = INVEST_r + WALRAS_r \qquad \forall r \in r2 \tag{MC10}$$

also includes a slack variable, rather than dropping an equation from the system (MC10). And second there is a market clearing condition on the relationship between each regions' trade balance, i.e.,

$$KAPWORSYS = \sum_r KAPWOR_r \tag{MC11}$$

where $KAPWORSYS$ is fixed at zero.

Table 4   **Equation and Variable Counts for the Global CGE Model**

Name	Equation	Number of Equations	Variable	Number of Variables	Globe
	EXPORTS BLOCK				
$PERDEF_{c,r,w}$	$PER_{c,r,w} = PWE_{c,r,w} * ER_r * \left(1 - \left(TEADJ_r * te_{c,r,w}\right)\right)$ $\forall c \in cer$	$(c*r*w)$	$PER_{c,r,w}$	$(c*r*w)$	YES
$PEDEF_{c,r}$	$PE_{c,r2} * QE_{c,r2} = \sum_w PER_{c,r2,w} * QER_{c,r2,w}$ $\forall c \in ce, r \in r2$	$(c*r2)$	$PE_{c,r}$	$(c*r2)$	NO
$PEDEF2_{c,r,w}$	$PER_{c,r,w} = PE_{c,r}$ $\forall c \in ct2, r \notin r2, w \in w2$	$(c*glo)$		$(c*glo)$	YES
$CET_{c,r}$	$QXC_{c,r} = at_{c,r} \left(\gamma_{c,r} * QE_{c,r}^{rhot_{c,r}} + \left(1 - \gamma_{c,r}\right) * QD_{c,r}^{rhot_{c,r}}\right)^{\frac{1}{rhot_{c,r}}}$ $\forall c \in \left(cd \cap ce\right), r \in r2$	$(c*r2)$	$QD_{c,r}$	$(c*r2)$	NO
$ESUPPLY_{c,r}$	$\dfrac{QE_{c,r}}{QD_{c,r}} = \left[\dfrac{PE_{c,r}}{PD_{c,r}} * \dfrac{\left(1 - \gamma_{c,r}\right)}{\gamma_{c,r}}\right]^{\frac{1}{(rhot_{c,r}-1)}}$ $\forall c \in \left(cd \cap ce\right), r \in r2$	$(c*r2)$	$QE_{c,r}$	$(c*r2)$	NO
$CET2_{c,r}$	$QXC_{c,r} = QD_{c,r}$ $\forall c \in \left(cd \cap cen\right), r \in r2$				NO
$CET3_{c,r}$	$QXC_{c,r} = QE_{c,r}$ $\forall c \in \left(cdn \cap ce\right), r \in r2$				NO
$TSHIP_{c,r}$	$QE_{c,r} = QM_{c,r}$ $\forall c \in ct2, r \notin r2$	$(c*glo)$	$QE_{c,r}$	$(c*glo)$	YES
$CETREQ_{c,r,w}$	$QER_{c,r,w} = QE_{c,r} * \left(\dfrac{PER_{c,r,w}}{PE_{c,r} * gammr_{c,r,w} * atr_{c,r}^{rhot_{c,r}^r}}\right)^{1/\left(rhot_{c,r}^r - 1\right)}$ $\forall c \in cer, r \in r2$	$(c*r2*w)$	$QER_{c,r,w}$	$(c*r2*w)$	NO
$CETREQ2_{c,r,}$	$QE_{c,r} = \sum_w QER_{c,r,w}$ $\forall c \in ct, r \notin r2$	$(c*glo)$			

Name	Equation	Number of Equations	Variable	Number of Variables	Globe
	IMPORTS BLOCK				
$PMRDEF_{c,r,w}$	$PMR_{c,r,w} = PWM_{c,r,w} * ER_r * \left(1 + \left(TMADJ_r * tm_{c,r,w}\right)\right)$ $\forall c \in cmr$	$(c*r*w)$	$PMR_{c,r,w}$	$(c*r*w)$	YES
$PMDEF_{c,r}$	$PM_{c,r} * QM_{c,r} = \sum_w PMR_{c,r,w} * QMR_{c,r,w} \qquad \forall c \in cm$	$(c*r)$	$PM_{c,r}$	$(c*r)$	YES
$PWMDEF_{c,r,w}$	$PWM_{c,r,w} = PWMFOB_{c,r,w} + \sum_{cp \in ct} margcor_{cp,c,r,w} * PT_{cp,r}$ $\forall c \in cmr$	$(c*r*w)$	$PWM_{c,r,w}$	$(c*r*w)$	YES
$ARMINGTON_{c,r}$	$QQ_{c,r} = ac_{c,r} \left(\delta_{c,r} * QM_{c,r}^{-rhoc_{c,r}} + \left(1-\delta_{c,r}\right) * QD_{c,r}^{-rhoc_{c,r}}\right)^{-\left(\frac{1}{rhoc_{c,r}}\right)}$ $\forall c \in \left(cx \cap cm\right), r \in r2$	$(c*r2)$	$QM_{c,r2}$	$(c*r2)$	NO
$COSTMIN_{c,r}$	$\dfrac{QM_{c,r}}{QD_{c,r}} = \left[\dfrac{PD_{c,r}}{PM_{c,r}} * \dfrac{\delta_{c,r}}{\left(1-\delta_{c,r}\right)}\right]^{\frac{1}{\left(1+rhoc_{c,r}\right)}} \qquad \forall c \in \left(cx \cap cm\right), r \in r2$	$(c*r2)$	$PD_{c,r2}$	$(c*r2)$	NO
$ARMINGTON2_{c,r}$	$QQ_{c,r} = QD_{c,r} \qquad \forall c \in \left(cx \cap cmn\right), r \in r2$				NO
$ARMINGTON3_{c,r}$	$QQ_{c,r} = QM_{c,r} \qquad \forall c \in \left(cxn \cap cm\right), r \in r2$				NO
$QTEQ_{c,r,w}$	$QT_{c,r,w} = \sum_{cp} \left(QMR_{cp,r,w} * margcor_{c,cp,r,w}\right) \qquad \forall c \in ct2, r \in r2$	$(c*r2*w)$	$QT_{c,r2,w}$	$(c*r2*w)$	NO
$ARMREQ_{c,r,w}$	$QMR_{c,r,w} = QM_{c,r} * \left(\dfrac{PMR_{c,r,w} * acr_{c,r}^{rhoc_{c,r}^r}}{PM_{c,r} * delta_{c,r,w}^r}\right)^{-1/\left(rhoc_{c,r}^r + 1\right)} \qquad \forall c \in cmr$	$(c*r*w)$	$QMR_{c,r,w}$	$(c*r*w)$	YES

Name	Equation	Number of Equations	Variable	Number of Variables	Globe
	COMMODITY PRICE BLOCK				
			PD_c		
$PQDEF_{c,r}$	$PQ_{c,r} * \left(1 + \left(TSADJ_r * ts_{c,r}\right)\right) * QQ_{c,r}$ $= \left(PD_{c,r} * QD_{c,r}\right) + \left(PM_{c,r} * QM_{c,r}\right)$ $\forall c \in \left(cd \cup cm\right), r \in r2$	$(c*r2)$	$PQ_{c,r}$	$(c*r2)$	NO
$PXCDEF_{c,r}$	$PXC_{c,r} = \dfrac{\left(PD_{c,r} * QD_{c,r}\right) + \left(PE_{c \in ce,r} * QE_{c \in ce,r}\right)}{QXC_c}$ $\forall c \in cx, r \in r2$	$(c*r2)$	$PXC_{c,r}$	$(c*r2)$	NO
	NUMERAIRE PRICE BLOCK				
$CPIDEF_r$	$CPI_r = \sum_c comtotsh_{c,r} * PQ_{c,r} \qquad \forall r \in r2$	$r2$	CPI_r	$r2$	NO
$PPIDEF_r$	$PPI_r = \sum_c vddtotsh_{c,r} * PD_{c,r} \qquad \forall r \in r2$	$r2$	PPI_r	$r2$	NO

Name	Equation	Number of Equations	Variable	Number of Variables	Globe
	PRODUCTION BLOCK				
$PXDEF_{a,r}$	$PX_{a,r} = \sum_c actcomactsh_{a,c,r} * PXC_{c,r} \quad \forall r \in r2$	$(a*r2)$	$PX_{a,r}$	$(a*r2)$	NO
$PVDEF_{a,r}$	$PV_{a,r} = \left(PX_{a,r} * \left(1-\left(TXADJ_r * tx_{a,r}\right)\right)\right) - \left(\sum_c PQ_{c,r} * comactco_{c,a,r}\right)$ $\forall r \in r2$	$(a*r2)$	$PV_{a,r}$	$(a*r2)$	NO
$PRODFN_{a,r}$	$QX_{a,r} = adces_{a,r} * \left[\sum_f \delta^x_{f,a,r} * FD^{-\rho^x_{a,r}}_{f,a,r}\right]^{-\frac{1}{\rho^x_{a,r}}} \quad \forall r \in r2$	$(a*r2)$	$QX_{a,r}$	$(a*r2)$	NO
$PROFITMAX_{f,a,r}$	$WF_{f,r} * WFDIST_{f,a,r}$ $= PV_{a,r} * adces_{a,r} * \left[\sum_f \delta^x_{f,a,r} * FD^{-\rho^x_{a,r}}_{f,a,r}\right]^{\left(\left(\frac{-1}{\rho^x_{a,r}}\right)-1\right)} * \delta^x_{f,a,r} * FD^{\left(-\rho^x_{a,r}-1\right)}_{f,a,r}$ $\forall r \in r2, \delta^x_{f,a,r}$	$(f*a*r2)$	$FD_{a,f,r}$	$(f*a*r2)$	NO
$QINTEQ_{c,r}$	$QINTD_{c,r} = \sum_a comactco_{c,a,r} * QX_{a,r} \quad \forall r \in r2, c \text{ int } d \text{ ???}$	$(c*r2)$	$QINTD_{c,r}$	$(c*r2)$	NO
$COMOUT_{c,r}$	$QXC_{c,r} = \sum_a actcomactsh_{a,c,r} * QX_{a,r} \qquad \forall r \in r2$	$(c*r2)$	$QXC_{c,r}$	$(c*r2)$	NO

Name	Equation	Number of Equations	Variable	Number of Variables	Globe
	FACTOR BLOCK				
$YFEQ_{f,r}$	$YF_{f,r} = \sum_a WF_{f,r} * WFDIST_{f,a,r} * FD_{f,a,r} \qquad \forall r \in r2$	$(f*r2)$	$YF_{f,r}$	$(f*r2)$	NO
$YFDISTEQ_{f,r}$	$YFDIST_{f,r} = \left(YF_{f,r} - \left(deprec_{f,r} * YF_{f,r}\right)\right) * \left(1 - \left(TYFADJ_r * tyf_{f,r}\right)\right)$ $\forall r \in r2$	$(f*r2)$	$YFDIST_{f,r}$	$(f*r2)$	NO
	HOUSEHOLD BLOCK				
$YHEQ_{h,r}$	$YH_{h,r} = \sum_f YFDIST_{f,r} \quad \forall r \in r2$	$(h*r2)$	$YH_{h,r}$	$(h*r2)$	NO
$HEXPEQ_{h,r}$	$HEXP_{h,r} = \left(YH_{h,r} * \left(1 - \left(TYHADJ_r * tyh_{h,r}\right)\right)\right)$ $* \left(1 - \left(SADJ_r * kaphsh_{h,r}\right)\right) \quad \forall r \in r2$	$(h*r2)$	$HEXP_r$	$(h*r2)$	NO
$QCDEQ_{c,r}$	$QCD_{c,r} = \dfrac{\left(\sum_h comhoav_{c,h,r} * HEXP_{h,r}\right)}{PQ_{c,r}} \qquad \forall r \in r2$	$(c*r2)$	$QCD_{c,h}$	$(c*r2)$	NO

Name	Equation	Number of Equations	Variable	Number of Variables	Globe
	GOVERNMENT TAXES BLOCK				
$MTAXEQ_r$	$MTAX_r = \sum_w \sum_c \left(TMADJ_r * tm_{c,r,w} * PWM_{c,r,w} * ER_r * QMR_{c,r,w} \right)$ $\forall r \in r2$	$r2$	$MTAX_r$	$r2$	NO
$ETAXEQ_r$	$ETAX_r = \sum_w \sum_c \left(TEADJ_r * te_{c,r,w} * PWE_{c,r,w} * ER_r * QER_{c,r,w} \right)$ $\forall r \in r2$	$r2$	$ETAX_r$	$r2$	NO
$STAXEQ_r$	$STAX_r = \sum_c \begin{pmatrix} TSADJ_r * ts_{c,r} * PQ_{c,r} \\ * \left(QINTD_{c,r} + QCD_{c,r} + QGD_{c,r} + QINVD_{c,r} \right) \end{pmatrix} \forall r \in r2$	$r2$	$STAX_r$	$r2$	NO
$ITAXEQ_r$	$ITAX_r = \sum_a \left(TXADJ_r * tx_{a,r} * PX_{a,r} * QX_{a,r} \right) \ \forall r \in r2$	$r2$	$INDTAX_r$	$r2$	NO
$FTAXEQ_r$	$FTAX_r = \sum_f \left(TYFADJ_r * tyf_{f,r} * \left(YF_{f,r} - \left(deprec_{f,r} * YF_{f,r} \right) \right) \right)$ $\forall r \in r2$	$r2$	$FTAX_r$	$r2$	NO
$HTAXEQ_r$	$HTAX_r = \sum_h \left(TYHADJ_r * tyh_{h,r} * YH_{h,r} \right) \qquad \forall r \in r2$	$r2$	$HTAX_r$	$r2$	NO

Name	Equation	Number of Equations	Variable	Number of Variables	Globe
	GOVERNMENT INCOME AND EXPENDITURE BLOCK				
$YGEQ_r$	$YG_r = MTAX_r + ETAX_r + STAX_r + ITAX_r + FTAX_r + HTAX_r$ $\forall r \in r2$	$r2$	YG_r	$r2$	NO
$QGDEQ_{c,r}$	$QGD_{c,r} = comgovconst_{c,r} * QGDADJ_r \qquad \forall r \in r2$	$(c*r2)$	$QGD_{c,r}$	$(c*r2)$	NO
$EGEQ_r$	$EG_r = \sum_c PQ_{c,r} * QGD_{c,r} \qquad \forall r \in r2$	$r2$	EG_r	$r2$	NO
	KAPITAL ACCOUNT BLOCK				
$TOTSAVEQ_r$	$TOTSAV_r = \left(\sum_h \begin{array}{c} \left(YH_{h,r} * \left(1 - \left(TYHADJ_r * tyh_{h,r} \right) \right) \right) \\ * \left(SADJ_r * kaphsh_{h,r} \right) \end{array} \right)$ $+ \sum_f deprec_{f,r} * YF_{f,r}$ $+ KAPGOV_r + \left(KAPWOR_r * ER_r \right) \qquad \forall r \in r2$	$r2$	$TOTSAV_r$	$r2$	NO
$QINVDEQ_{c,r}$	$QINVD_{c,r} = IADJ_r * invconst_{c,r} \qquad \forall r \in r2$	$(c*r2)$	$QINVD_{c,r}$	$(c*r2)$	NO
$INVESTEQ_r$	$INVEST_r = \sum_c \left(PQ_{c,r} * QINVD_{c,r} \right) \qquad \forall r \in r2$	$r2$	$INVEST_r$	$r2$	NO

Name	Equation	Number of Equations	Variable	Number of Variables	Globe
	MARKET CLEARING BLOCK				
$FMEQUIL_{f,r}$	$FS_{f,r} = \sum_a FD_{f,a,r} \qquad \forall r \in r2$	$(f*r2)$	$FS_{f,r}$	$(f*r2)$	NO
$QEQUIL_{c,r}$	$QQ_{c,r} = QINTD_{c,r} + QCD_{c,r} + QGD_{c,r} + QINVD_{c,r}$ $\forall c \in (cd \cup cm), r \in r2$	$(c*r2)$	$QQ_{c,r}$	$(c*r2)$	NO
$KAPGOVEQ_r$	$KAPGOV_r = YG_r - EG_r \qquad \forall r \in r2$	$r2$	$KAPGOV_r$	$r2$	NO
$KAPEQUIL_r$	$KAPWOR_{r2} = \left(\sum_w \sum_c PWM_{c,r2,w} * QMR_{c,r2,w} \right)$ $- \left(\sum_w \sum_c PWE_{c,r2,w} * QER_{c,r2,w} \right) \qquad \forall r \in r2$	$r2$	$KAPWOR_r$	$r2$	NO
$KAPREQUIL_{r,w}$	$KAPREG_{r,w} = \left(\sum_c PWM_{c,r,w} * QMR_{c,r,w} \right)$ $- \left(\sum_c PWE_{c,r,w} * QER_{c,r,w} \right) \qquad \forall r \in r2$	$r2$	$KAPREG_{r,w}$	$r2$	NO
$GLOBEQUIL_{ct,r2}$	$\sum_w QT_{c,r,w} = QER_{c,r,w} \qquad \forall c \in ct2, r \in r2$	$(ct,r2)$	$PWE_{ct,,glo,w}$	$(ct*r2)$	NO
$TRCONP_{c,r,w}$	$PWMFOB_{c,r,w} = PWE_{c,rp,wp} \qquad \forall c \in cmr$	$(c*r*w)$	$PWMFOB^{c,r,w}$	$(c*r2*w)$	YES
$TRCONQ_{c,r,w}$	$QMR_{c,r,w} = QER_{c,rp,wp} \qquad \forall c \in cmr$	$(c*r2*w)$		$(c*r2*w)$	NO
$PTDEF_{c,r}$	$PT_{c,r} = PWE_{c,r,w} \qquad \forall c \in ct2, r \in r2$	$(ct,r2)$	$PT_{ct,r2}$	$(ct,r2)$	NO
$WALRASEQ_r$	$TOTSAV_r = INVEST_r + WALRAS_r \qquad \forall r \in r2$	$r2$	$WALRAS_r$	$r2$	NO
$SYSEQUIL$	$KAPWORSYS = \sum_r KAPWOR_r$	1	$KAPWORSYS$	1	NO

Name	Equation	Number of Equations	Variable	Number of Variables
	MODEL CLOSURE			
	All globe transactions are in world dollars (i.e. of the reference region)	$\overline{ER}_{glo}$		
	There is no current account equation for the globe.	AND $\overline{KAPWOR}_{glo}$		
	Assign the reference region, eliminating one variable; add the constraint that the sum of KAPWOR across r2 must be zero	$\overline{KAPWORSYS}$	$\overline{ER}_{ref}$	
	For the non-reference regions, one can fix either the exchange rate or the current account balance	$\overline{ER}_{nonref}$ **or**	$\overline{KAPWOR}_{nonref}$	1
		$\overline{SADJ}$ **or** $\overline{IADJ}$ **or**	$\overline{INVEST}$	1
	All **but** two of $\overline{TMADJ}, \overline{TSADJ}, \overline{TEADJ}, \overline{TXADJ}, \overline{TYHADJ}, \overline{QGDADJ}, \overline{KAPGOV}, \overline{EG}$			6
			$\overline{FS}_f$	3
		$\overline{CPI}$ **or**	$\overline{PPI}$	1
		$f + 12c + (4+f)a + 14$		$2f + 12c + (4+f)a + 23$

MODEL CLOSURE CONDITIONS OR RULES

In mathematical programming terms the model closure conditions are, at their simplest, a matter of ensuring that the numbers of equations and variables are consistent. However the economic theoretic dimensions of model closure rules are more complex, and, as would be expected in the context of an economic model, more important. The essence of model closure rules is that they define important and fundamental differences in perceptions of how an economic system operates (see Sen, 1963; Pyatt, 1987; Kilkenny and Robinson, 1990). The closure rules can be perceived as operating on two levels; on a general level whereby the closure rules relate to macroeconomic considerations, e.g., is investment expenditure determined by the volume of savings or exogenously, and on a specific level where the closure rules are used to capture particular features of an economic system, e.g., the degree of intersectoral capital mobility.

This model allows for a range of both general and specific closure rules. The discussion below provides details of some of the options available with this formulation of the model by reference to the accounts to which the rules refer.

FOREIGN EXCHANGE ACCOUNT CLOSURE

In the default closure of the foreign exchange accounts the exchange rate for the reference region is fixed, i.e.,

$$ER_{ref} = \overline{ER}_{ref} \tag{C1a}$$

and the balances on the current account for all the non reference regions are flexible, i.e.,

$$KAPWOR_{r2} = \overline{KAPWOR0}_{r2} \quad \forall ref \notin r2 . \tag{C1b}$$

The Globe account is distinct in that does not have its own exchange rate and hence all its exchanges are conducted in the currency units of the reference region. Hence its exchange rate is fixed as

$$ER_{glo} = \overline{ER}_{ref} \tag{C1c}$$

in addition the Globe cannot run a trade balance since it is treated as simple transfer

region with no transaction costs, so the trade balance for Globe is fixed as

$$KAPWOR_{glo} = \overline{KAPWOR0_{glo}} = 0.0 \,. \tag{C1d}$$

The exchange rate for the reference region serves as the global numéraire, while the

combination of C1b and C1d means that one set of trade balances has been dropped. To

ensure that all trade balances are accounted for there is a need for a system equilibrium

such that

$$KAPWORYS = \overline{KAPWORSYS0} = 0.0 \,. \tag{C1e}$$

ensures the model remains square.

CAPITAL ACCOUNT CLOSURE

To ensure that aggregate savings equal aggregate investment, the determinants of either

savings or investment must be fixed. This is achieved by fixing the saving rates for

households or the volumes of commodity investment. This involves fixing either the

savings rates adjusters (C2a) or the investment volume adjuster (C2b), i.e.,

$$SADJ_r = \overline{SADJ_r} \tag{C2a}$$

or

$$IADJ_r = \overline{IADJ_r} \tag{C2b}$$

Note that fixing the investment volume adjuster (C2b) means that the value of investment

expenditure might change due to changes in the prices of investment commodities

(*PQD*). Note that if the *SADJ*s are fixed the adjustment takes place through

equiproportionate changes in the savings rates of households. It is of course not necessary

to assume the same savings/investment determinants in all regions, although it is

necessary to ensure the decisions are made for all regions.

Fixing savings, and thus deeming the economy to be savings-driven, can be

considered a Neo-Classical approach. Closing the economy by fixing investment

however makes the model reflect the Keynesian investment-driven assumption for the operation of an economy. Note that there are other sources of potential savings for region – the government and the trade balances. The magnitudes of these other savings sources can also be controlled through the closure rules (see below).

GOVERNMENT ACCOUNT CLOSURE

The closure rules for the government account are slightly more tricky because they are important components of the model that are used to investigate fiscal policy considerations. The base specification uses the assumption that government savings are a residual; when the determinants of government income and expenditure are 'fixed', government savings must be free to adjust.

Thus in the base specification all the tax rates are fixed by declaring the tax rates as parameters and then fixing all the tax rate scaling factors (C4a – C4f), i.e.,

$$TMADJ_r = \overline{TMADJ}_r \tag{C3a}$$

$$TEADJ_r = \overline{TEADJ}_r \tag{C3b}$$

$$TSADJ_r = \overline{TSADJ}_r \tag{C3c}$$

$$TXADJ_r = \overline{TXADJ}_r \tag{C3d}$$

$$TYFADJ_r = \overline{TYFADJ}_r \tag{C3e}$$

$$TYADJ_h = \overline{TYADJ}_h \tag{C3f}$$

Consequently changes in tax revenue to the government are consequences of changes in the other variables that enter into the tax income equations (C3a to C3f).

In the base specification government expenditure is controlled by fixing the volumes of commodity demand (QGD) through the government demand adjuster ($QGDADJ$), i.e.,

$$QGDADJ_r = \overline{QGDADJ}_r \tag{C3g}$$

Alternatively the value of government expenditure can be fixed, i.e.,

$$EG_r = \overline{EG}_r . \tag{C3h}$$

This specification ensures that all the parameters that the government can/does control are fixed and consequently that the only determinants of government income and expenditure that are free to vary are those that the government does not <u>directly</u> control. Hence the equilibrating condition is that government savings, the internal balance, is not fixed.

If however the model requires government savings to be fixed (C4i), i.e.,

$$KAPGOV_r = \overline{KAPGOV}_r \tag{C3i}$$

then either government income or expenditure must be free to adjust. Such a condition might reasonably be expected in many circumstances, e.g., the government might define an acceptable level of borrowing or such a condition might be imposed externally.

In its simplest form this can be achieved by allowing one of the previously fixed adjusters (C4a to C4f) to vary. Thus if the sales tax adjuster (*TSADJ*) is made variable then the sales tax rates will be varied equiproportionately so as to satisfy the internal balance condition. More complex experiments might result from the imposition of multiple conditions, e.g., a halving of import duty rates coupled with a reduction in government deficit, in which case the variables *TMADJ* and K*APGOV* would also require resetting. But these conditions might create a model that is infeasible, e.g., due to insufficient flexibility through the import duties mechanism, or unrealistically high rates of import duties. In such circumstances it may be necessary to allow adjustments in multiple tax adjusters. One method then would be to fix the tax adjusters to move in parallel with each other.

However, if the adjustments only take place through the tax rate scaling factors the relative tax rates will be fixed. To change relative tax rates it is necessary to change the

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relevant tax parameters. Typically such changes would be implemented in policy experiment files rather than within the closure section of the model.

NUMÉRAIRE

The model specification allows for a choice of two price normalisation equations, the consumer price index and a producer price index, i.e.,

$$CPI_r = \overline{CPI}_r \qquad\qquad\qquad\qquad\text{(C4a)}$$

or

$$PPI_r = \overline{PPI}_r. \qquad\qquad\qquad\qquad\text{(C4b)}$$

A *numeraire* is needed to serve as a base since the model is homogenous of degree zero in prices and hence only defines relative prices.

FACTOR MARKET CLOSURE

The factor market closure rules are more difficult to implement than many of the other closure rules. Hence the discussion below proceeds in three stages; the first stage sets up a basic specification whereby all factors are deemed perfectly mobile, the second stage introduces a more general specification whereby factors can be made activity specific and allowance can be made for unemployed factors, while the third stage introduces the idea that factor market restrictions may arise from activity specific characteristics, rather than the factor inspired restrictions considered in the second stage.

Full Factor Mobility and Employment Closure

This factor market closure requires that the total supply of and total demand for factors equate. The total supplies of each factor are determined exogenously and hence

$$FS_{f,r} = \overline{FS}_{f,r} \qquad\qquad\qquad\qquad\text{(C5a)}$$

defines the first set of factor market closure conditions. The demands for factor f by activity a in region r and the wage rates for factors are determined endogenously. But the model specification includes the assumption that the wage rates for factors are averages,

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by allowing for the possibility that the payments to notionally identical factors might vary across activities through the variable that captures the 'sectoral proportions for factor prices'. These proportions are assumed to be a consequence of the use made by activities of factors, rather than of the factors themselves, and are therefore assumed fixed, i.e.,

$$WFDIST_{f,a,r} = \overline{WFDIST_{f,a,r}} \ . \tag{C5b}$$

Finally bounds are placed upon the average factor prices, i.e.,

$$\begin{aligned} \text{Min } WF_{f,r} &= 0 \\ \text{Max } WF_{f,r} &= +\text{infinity} \end{aligned} \tag{C5c}$$

so that meaningful results are produced.

Factor Immobility and/or Unemployment Closures

More general factor market closures wherein factor immobility and/or factor unemployment are assumed can be achieved by determining which of the variables referring to factors are treated as variables and which of the variables are treated as factors. If factor market closure rules are changed it is important to be careful to preserve the equation and variable counts when relaxing conditions, i.e., converting parameters into variables, and imposing conditions, i.e., converting variables into parameters, while preserving the economic logic of the model.

A convenient way to proceed is to define a block of conditions for each factor. For this model this amounts to defining the following possible equations

$$FS_{fact,r} = \overline{FS}_{fact,r}$$

$$WFDIST_{fact,a,r} = \overline{WFDIST}_{fact,a,r}$$

$$\text{Min } WF_{fact,r} = 0$$

$$\text{Max } WF_{fact,r} = +\text{infinity}$$

$$FD_{fact,a,r} = \overline{FD}_{fact,a,r} \tag{C5d}$$

$$WF_{fact,r} = \overline{WF}_{fact,r}$$

$$WFDIST_{fact,activ,r} = \overline{WFDIST}_{fact,activ,r}$$

$$\text{Min } FS_{fact,r} = 0$$

$$\text{Max } FS_{fact,r} = +\text{infinity}$$

where *fact* indicates the specific factor and *activ* a specific activity. The block of equations in (C5d) includes all the variables that were declared for the model with reference to factors plus extra equations for *WFDIST*, i.e., $WFDIST_{fact,activ,r} = \overline{WFDIST}_{fact,activ,r}$, whose role will be defined below. The choice of which equations are binding and which are not imposed will determine the factor market closure conditions.

As can be seen the first four equations in the block (C5d) are the same as those in the 'Full Factor Mobility and Employment Closure'; hence ensuring that these four equations are operating for each of the factors is a longhand method for imposing the 'Full Factor Mobility and Employment Closure'. Assume that this set of conditions represents the starting points, i.e., the first four equations are binding and the last five equations are not imposed.

Assume now that it is planned to impose a short run closure on the model, whereby a factor is assumed to be activity specific, and hence there is no inter sectoral factor mobility. Typically this would involve making capital activity specific and immobile, although it can be applied to any factor. This requires imposing the condition that factor demands are activity specific, i.e., the condition

$$FD_{fact,a,r} = \overline{FD}_{fact,a,r} \tag{C5e}$$

must be imposed. But the returns to this factor in different uses (activities) must now be allowed to vary, i.e., the condition

$$WFDIST_{fact,a,r} = \overline{WFDIST}_{fact,a,r} \qquad \text{(C5f)}$$

must now be relaxed.

The number of imposed conditions is equal to the number of relaxed conditions, which suggests that the model will still be consistent. But the condition fixing the total supply of the factor is redundant since if factor demands are fixed the total factor supply cannot vary. Hence the condition

$$FS_{fact,r} = \overline{FS}_{fact,r} \qquad \text{(C5g)}$$

is redundant and must be relaxed. Hence at least one other condition must be imposed to restore balance between the numbers of equations and variables. This can be achieved by fixing one of the sectoral proportions for factor prices for a specific activity, i.e.,

$$WFDIST_{fact,activ,r} = \overline{WFDIST}_{fact,activ,r} \qquad \text{(C5h)}$$

which means that the activity specific returns to the factor will be defined relative to the return to the factor in *activ*.[6]

Start again from the closure conditions for full factor mobility and employment and then assume that there is unemployment of one or more factors in the economy; typically this would be one type or another of unskilled labour. If the supply of the unemployed factor is perfectly elastic, then activities can employ any amount of that factor at a fixed price. This requires imposing the condition that

$$WF_{fact,r} = \overline{WF}_{fact,r} \qquad \text{(C5i)}$$

and relaxing the assumption that the total supply of the factor is fixed at the base level, i.e., relaxing

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[6]   It can be important to ensure a sensible choice of reference activity. In particular this is important if a factor is not used, or little used, by the chosen activity.

$$FS_{fact,r} = \overline{FS}_{fact,r} \tag{C5j}$$

It is useful however to impose some restrictions on the total supply of the factor that is unemployed. Hence the conditions

$$\text{Min } FS_{fact,.r} = 0$$
$$\text{Max } FS_{fact,r} = +\text{infinity} \tag{C5k}$$

can be imposed.[7]

Activity Inspired Restrictions on Factor Market Closures

There are circumstances where factor use by an activity might be restricted as a consequence of activity specific characteristics. For instance it might be assumed that the volume of production by an activity might be predetermined, e.g., known mineral resources might be fixed and/or there might be an exogenously fixed restriction upon the rate of extraction of a mineral commodity. In such cases the objective might be to fix the quantities of all factors used by an activity, rather than to fix the amounts of a factor used by all activities. This is clearly a variation on the factor market closure conditions for making a factor activity specific.

If all factors used by an activity are fixed, this requires imposing the conditions that

$$FD_{f,activ,r} = \overline{FD}_{f,activ,r} \tag{C5l}$$

must be imposed, where *activ* refers to the activity of concern. But the returns to these factors in this activities must now be allowed to vary, i.e., the conditions

$$WFDIST_{f,activ,r} = \overline{WFDIST}_{f,activ,r} \tag{C5m}$$

must now be relaxed. In this case the condition fixing the total supply of the factor is not redundant since only the factor demands by *activ* are fixed and the factor supplies to be allocated across other activities are the total supplies unaccounted for by *activ*.

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[7]   If the total demand for the unemployed factor increases unrealistically in the policy simulations then it is possible to place an upper bound of the supply of the factor and then allow the wage rate from that factor to vary.

Such conditions can be imposed by extending the blocks of equations for each factor in the factor market closure section. However, it is often easier to mange the model by gathering together factor market conditions that are inspired by activity characteristics after the factor inspired equations. In this context it is useful to note that when working in GAMS that the last condition imposed, in terms of the order of the code, is binding and supersedes previous conditions.

6.   IMPLEMENTATION AND COMPLEMENTARY PROGRAMMES

The current version of the model is implemented as a mixed complementarity problem (MCP) in GAMS 250 21.5 using the Path solver. In a model with 15 sectors, 4 factors and 14 regions that generates some 24,250 equations and variables and the initial, or replication, solve takes some 15 seconds on a well equipped Pentium 4 2.6MHz PC, while the entire run for a series of 11 simple experiments run in a loop takes about 75 seconds, including writing out a comprehensive set of results to a series of GDX files.

However once a programme is established the time consuming activities are those associated with the generation of new aggregations and the analyses of results. In order to address these problems as pair of Excel based programmes, using VBA, and a series of GAMS programmes have been developed.

DATABASE AGGREGATION

The Excel based programme for aggregating the database is called SAMGator (PROVIDE, 2004b). This is general aggregation programme that uses Excel to provide a front end that simplifies the creation of the set files required for the mapping aggregations. The user declares, with descriptors, the accounts required in the new aggregation and identifies those accounts in the database that will be aggregated to form the new accounts; this is all done using point and click commands in an Excel worksheet. Once all the new accounts have been declared and assigned, and provided all the data in the original database are accounted for, a command triggers the creation of the mapping files. Finally the user triggers the running of the aggregation programme from within

Excel. At this point SAMGator generates a GAMS programme file, *.gms, runs that programme and writes out the results to GDX and/or Excel.

ANALYSES OF RESULTS

The management and organisation of results from large CGE models can be both time consuming and confusing due to the large number of data points generated, e.g., the model with 15 sectors, 4 factors and 14 regions when run with 11 experiments generates more than 500,000 data points even when only running a limited set of analyses programmes. An Excel based programme for analysing, organising and summarising results from CGE models called SeeResults (PROVIDE, 2004a) has been developed for the interactive reading of GAMS model results that have been stored in GDX format.

The GDX format is technically superlative, with GDX files being both extremely fast and small. Once the result data are in GDX format, they can be viewed using GAMSIDE or GDXViewer, a specialised utility for viewing GDX files and both of these include basic facilities for changing data orientation and the GDXViewer also includes basic charting (plot) facilties. While these are useful, there are a number of limitations. Filtering ability is limited, which can make it difficult to compare results within a smaller subset of elements from a large set. Charting facilities in GDXViewer are limited and not designed for presentation quality output. It is not possible to manipulate data, change formatting, perform calculations or cut and paste data to other applications, although there are data output facilities. In short, these facilities are suitable for viewing raw data initially but are not a complete solution for the processing of model results.

Among proprietary programmes Excel is the logical choice; it has reasonably good charting facilities, is excellent for general data manipulation and provides the means to format data for presentation purposes. It can also provide limited database functionality such as reorientation and filtering via the pivot table feature. It is also useful as a means to distribute data, because it has a (very) wide user base. But it is often tedious getting large amounts of data into Excel and can produce extremely large files that are difficult to transfer. SeeResults automates much of this process; it avoids overly large Excel files by working interactively with GDX files, that remain the files in which data are stored, and

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coordinates information that assists with the categorisation, classification and labeling of the results.

The guiding principle behind SeeResults to make use of the functionality of GDX and Excel; thereby avoiding the need to develop additional standalone programme. Excel is conceptually a very powerful programming environment, allowing use of the spreadsheet itself as a data construct and combining the power of Visual Basic with the ability to use spreadsheet functions in Visual Basic code. A major usage of Excel functionality is the use of Pivot Tables for data reorientation and filtering in multidimensional data. Excel's pivot tables are ideally suited to the task of storing and presenting reasonable amounts of data and allowing the display format to be changed after data has been imported to Excel. It performs SeeResults technically demanding data handling tasks more efficiently than would have been possible using custom Visual Basic code.

7.   CONCLUDING COMMENTS

This paper has described the first version of a new global CGE model. The model described here contains relatively simple behavioural relationships although it requires a programme that contains a number of technically sophisticated features. Moreover it is capable of being implemented with any aggregation of the GTAP database. This version of the model will be made generally available after further testing.

However this is work in progress and additional features are being added to the model on a continuing basis; this working paper will therefore be subject to periodic updating when substantive new features have been added and adequately tested.

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