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Part 1. The Model and Studies by Country

From stylized to applied models: Building multisector CGE models for policy analysis

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Abstract

This paper describes how to build multisector computable general equilibrium models for policy analysis. The article presents the social accounting matrix (SAM) that provides the conceptual framework linking together different components of the model and furnishes much of the data as well. This is followed by the equations of the core CGE model and by a description of how the core model is implemented using the GAMS software. The article proceeds to describe how the model's benchmark data and parameters are derived from the SAM. The final section uses data from an African country to consider how the GAMS model can be applied to evaluate the economic impact of capital inflows. © 1999 Elsevier Science Inc. All rights reserved.

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1. Introduction

This article describes how to build multisector computable general equilibrium (CGE) models for policy analysis. Although stylized models are useful, they represent only the starting point in the application of empirical models to policy analysis. The multisector CGE model provides a versatile empirical simulation laboratory for analyzing quantitatively the effects of economic policies and external shocks on the domestic economy.

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Although stylized models may tell us the *direction* of change in response to a tariff increase, often we are concerned more with the *magnitude* of the change. Policymakers wish to know, “By how much will exports and imports decline if we raise import tariffs?” Furthermore, many of the policies under consideration refer to specific sectors, not a large aggregate. In designing tariff policy, for example, policymakers are unlikely to raise tariffs on all traded products, but perhaps only on intermediate or capital goods. Finally, large, more detailed models are required to capture institutional arrangements characterizing particular countries.

The plan of this article is as follows. In Section 2, we discuss the social accounting matrix (SAM) that provides the conceptual framework linking together different components of the model and furnishes much of the data as well. In Section 3, we present the equations of the core CGE model. In Section 4, we describe how this core model is implemented using the GAMS software.[1] In Section 5, we discuss how most of the model’s benchmark data and parameters are derived from the SAM. Finally, in Section 6, we use data for Cameroon to consider how the GAMS model can be applied to analyze the economic effect of capital inflows (or “Dutch disease”) in Cameroon.

2. The SAM and CGE models

Presentation of an aggregate SAM for the economy is a useful way to set the stage for discussing the equations of the core model. A SAM is the synthesis of two well-known ideas in economics. The first derives from the input-output figure, which portrays the system of interindustry linkages in the economy. The purchase of an intermediate input by one sector represents the sale of that same input by another sector. While this transaction is entered in a single cell in the input-output figure, it appears in the accounts of the two different sectors using traditional double-entry bookkeeping. The SAM generalizes the input-output idea that one sectors’s purchase is another sector’s sale to include *all* transactions in the economy, not just interindustry flows. Any flow of money from, say, a household to a productive sector (representing the purchase of that sector’s output by the household), or from a household to the government (representing tax payments), is recorded in the SAM as an expenditure *by* some actor (the column) *to* some other actor (the row).

The second idea embodied in the SAM, derived from national income accounting, is that income always equals expenditure. Although true for the economy as a whole, the SAM requires a balance in the accounts of every factor in the economy. For example, the income from sales in the agriculture sector must equal its total expenditures on intermediate inputs, labor, imports, and capital services. Traditionally, this is captured in double-entry bookkeeping by the requirement that the two sides of the ledger must be equal. In the SAM, incomes appear along the rows, and expenditures down the columns; thus the budget constraints require that the row sum (income) must equal the column sum (expenditure).

The SAM also distinguishes between “activities” and “commodities,” allowing for two different effects. First, it permits more than one type of activity to produce the same commodity, thereby allowing for different production technologies. For example, small- and large-scale farmers may produce the same crop (a single "commodity"), but with different factor intensities (two or more "activities"). Second, this treatment addresses several difficult problems that arise from dealing with imports. If imports are at all competitive with domestically produced goods (which is usually the case), then domestic demand will consist of both types of goods. However, only domestic goods are exported. Separating activity accounts (or the domestic *production* of goods) from commodity accounts (the domestic *demand* for goods) enables us to portray this difference.

Fig 1. Schematic Social Accounting Matrix (SAM)

Receipts	Expenditures						
	Activities	Commodities	Factors	Households	Government	Capital	Rest of world
Activities		Domestic sales					Exports
Commodities	Intermediate inputs			Private consumption	Government consumption	Investment	
Factors	Value added						
Households			Allocation matrix		Government transfers		
Government	Indirect taxes	Import tariffs		Income taxes			
Capital				Private savings	Government savings		Foreign savings
Rest of world		Imports					

Reading first across the *activity row* in the schematic SAM in Figure 1, we observe that total income derives from domestic sales to the commodity account and exports (sales to the rest of the world). The *activity column* contains all expenditures on inputs into the production process: on intermediate inputs, on value added, and on indirect taxes. The sum of these input expenditures should equal gross output sales. The commodity account can be thought of as a supermarket that carries both foreign and domestic goods. The *commodity column* shows purchases of domestic products from the activity account and purchases of imports from the rest of the world; it also pays import tariffs to the government (although the incidence is on consumers, since the market prices are higher by the amount of the tariffs). The *commodity row* shows how the total supply of commodities is demanded by domestic purchasers, including intermediate inputs, household and government consumption, and investment goods.

In the *factors account*, the value added received by factors of production is allocated to households (via the allocation matrix). The *household account* shows that households, in turn, divide this income, as well as any transfers from the government, between private consumption of goods, income taxes, and private savings. Similarly, in the *government account*, the government receives income from taxes (including tariffs, indirect taxes, and income taxes) and spends it on consumption, transfers to households, and savings. The last two rows and columns contain familiar national accounts identities. The *capital account* reflects the equality between savings (the row, comprised of private, government, and foreign components), and investment (the column). The *rest of the world account* represents the equality between foreign exchange expenditures (imports) and foreign exchange earnings (exports plus foreign savings).

The different accounts in the SAM delineate the boundaries of an economywide model.[2] Specification of a "complete" model requires that the market, behavioral, and system relationships embodied in each account in the SAM be described in the model. The *activity, commodity,* and *factor* accounts all require the specification of market behavior (supply, demand, and clearing conditions). The *household* and *government* accounts embody the private household and public sector budget constraints (income equals expenditure). Finally, the *capital* and *rest of world* accounts represent the macroeconomic requirements for internal (saving equals investment) and external (exports plus capital inflows equal imports) balance.

3. Equations of the core CGE model

The SAM discussed in the previous section provides a schematic portrayal of the circular flow of income in the economy: from activities and commodities, to factors of production, to institutions, and back to activities and commodities again. The presentation of equations of the core CGE model follows this same pattern of income generation. First, we present equations defining the price system, followed by equations that describe production and value-added generation. Next are equations that describe the mapping of value added into institutional income. The circular flow is then completed by equations showing the balance between supply and demand for goods by the various actors. Finally, there are a number of "system constraints" that the model economy must satisfy. These include both market clearing conditions and the choice of macro "closure" for the model.

Some notational conventions are followed consistently. Endogenous variables are presented in upper case, while parameters and exogenous variables are always lower case or greek letters. Indices appear as lower case subscripts, and consist of sectors (i and j), primary factors of production (f), and households (h, containing two elements, *cap* and *lab*). In a few equations, an index is replaced by a specific entry from the set. Appendix 1 to this article gathers all of the equations into a summary figure and provides a dictionary of variable and parameter names.

3.1. Price equations

Table 1 presents the equations defining prices in the model. On the import side, the model incorporates the "small country" assumption: world prices (pw^m) are exogenous. On the export side, for some sectors, a downward sloping world demand curve is assumed, so the world price (PW^e) is endogenous; for other sectors, the small country assumption is retained, so that world prices are exogenous. In Equations 1 and 2, the domestic price of

Table 1: Price Equations

(1)	$P_i^m = pw_i^m(1 + t_i^m)R$
(2)	$P_i^e = PW_i^e(1 + t_i^e)R$
(3)	$P_i^q = \frac{P_i^d \cdot D_i + P_i^m \cdot M_i}{Q_i}$
(4)	$P_i^x = \frac{P_i^d \cdot D_i + P_i^e \cdot E_i}{X_i}$
(5)	$P_i^v = P_i^x(1 - t_i^x) - \sum_j P_j^q \cdot a_{ji}$
(6)	$P_i^k = \sum_j P_j^q \cdot b_{ji}$
(7)	$PINDEX = \frac{GDPVA}{RGDP}$

imports (P^m) and of exports (P^e) is the tariff- or subsidy-inclusive world price times the exchange rate (R).

Equations 3 and 4 describe the prices for the composite commodities Q and X. Q represents the CES aggregation of sectoral imports (M) and domestic goods supplied to the domestic market (D). X is total sectoral output, which is a CET aggregation of goods supplied to the export market (E) and goods sold on the domestic market (D).[3]

Equation 5 defines the sectoral price of value-added, or "net" price (P^v), which is the output price minus unit indirect taxes (t^x) and the unit cost of intermediate inputs (based on the fixed input-output coefficients, a_{ij}). The product $P^v \cdot X$ equals sectoral value added at factor cost, which appears as a payment by the *activities account* to the *primary factor account* in the SAM in Figure 1.

Equation 6 gives the price (P^k) of a unit of capital installed in Sector i. The price is sectorally differentiated, reflecting the fact that capital used in different sectors is heterogeneous. For example, a unit of capital installed in an agricultural sector can have a different composition than a unit installed in an industrial sector (e.g., more machinery and fewer buildings in the agricultural sector compared with the industrial sector). The sectoral composition of capital goods by sector of origin (that is, machinery, construction, and so on) is contained in the columns of the capital coefficients matrix, b_{ij}. Because each column of this matrix sums to unity, P^k for each sector is simply the weighted average of the unit cost of capital goods required to create a unit of capital in each investing sector.

This core CGE model is static, with the economywide capital stock fixed exogenously. Within the single period, the model does generate savings, investment, and the demand for capital goods. However, by assumption, these capital goods are not installed during the period, so that investment simply represents a demand category with no effect on supply in the model. Hence, the heterogeneity of capital is of limited importance in the static model, because its only effect will emerge through its effect on the sectoral structure of investment final demand. In dynamic models, the heterogeneity assumption can be very important and affect the properties of different growth paths.

Finally, Equation 7 defines an aggregate price index (PINDEX), which is defined as the GDP deflator (nominal GDP, GDPVA, divided by real GDP, RGDP). This index provides the numeraire price level against which all relative prices in the model will be measured. The choice of a numeraire is necessary because the core CGE model can determine relative prices only. The GDP deflator represents a convenient choice for the *numeraire* in an applied model because it is usually readily available from available national accounts data. Other common *numeraire* choices include another price index (such as a consumer or producer price index), or a single price (such as the exchange rate or a wage rate).

3.2. Quantity equations

Table 2: Quantity Equations

$$(8)\quad X_i = a_i^D \prod_f FDSC_{if}^{\alpha_{if}} \qquad (FDSC_{i1} = capital\ stock)$$

$$(9)\quad WF_f \cdot wfdist_{if} = P_i^v \cdot \alpha_{if} \frac{X_i}{FDSC_{if}}$$

$$(10)\quad INT_i = \sum_j a_{ij} \cdot X_j$$

$$(11)\quad X_i = a_i^T [\gamma_i E_i^{\rho_i^T} + (1 - \gamma_i) D_i^{\rho_i^T}]^{1/\rho_i^T 1}$$

$$(12)\quad E_i = D_i \left[\frac{P_i^e (1 - \gamma_i)}{P_i^d \cdot \gamma_i} \right]^{1/\rho_i^T}$$

$$(13)\quad E_i = econ_i \left[\frac{PW_i^e}{pwse_i} \right]^{\eta_i}$$

$$(14)\quad Q_i = a_i^C [\delta_i M_i^{-\rho_i^C} + (1 - \delta_i) D_i^{-\rho_i^C}]^{-1/\rho_i^C}$$

$$(15)\quad M_i = D_i \left[\frac{P_i^d \cdot \delta_i}{P_i^m (1 - \delta_i)} \right]^{1/1+\rho_i^C}$$

Table 2 contains the block of quantity equations, which describe the supply side of the model. The functional forms chosen must satisfy certain restrictions of general equilibrium theory. Equations 8 through 10 define the production technology and demand for factors.

Equation 11 contains the CET transformation functions combining exports and domestic sales, and Equation 12 shows the corresponding export supply functions, which depend on relative prices (P^e/P^d). Equation 13 gives the world export demand function for sectors in which the economy is assumed to have some market power (and thereby faces a downward sloping demand curve). Equations 14 and 15 give the CES aggregation functions, describing how imports and domestic products are demanded, and the corresponding import demand functions, which depend on relative prices (P^d/P^m).

The production function is nested. At the top level, output is a fixed coefficients function of real value added and intermediate inputs. Real value added is a Cobb-Douglas function of capital and labor. The capital input is a fixed coefficients aggregate of capital goods, but only the aggregate is shown in the production function of Equation 8. Intermediate inputs are required according to fixed input-output coefficients (Equation 10), and each intermediate input is a CES aggregation of imported and domestic goods.

The specification of production technology and factor demands in these equations embodies a useful simplification often used in CGE models. To be complete, the production function (Equation 8) should include *all* inputs as arguments: capital, labor, and intermediate inputs. The factor demand conditions in Equation 9 would then be written (dropping sectoral subscripts):

$$Factor\ Price\ =\ Marginal\ Revenue\ Product = (1 - t^x) \cdot P^x \cdot \frac{\partial X}{\partial F}$$

where F is the full set of factor inputs. The nesting described above would be taken into account by using the chain rule. In Equation 8, we instead specify the production function only as a function of *primary* factors, defined as capital and labor. Intermediate input demands are given in Equation 10, whereas Equation 9 shows the demand for primary factors in the following form (again dropping sectoral subscripts):

$$Factor\ Price = P^v \cdot \frac{\partial X}{\partial FDSC}$$

where FDSC now refers only to primary factors, and P^v is the value added price (Equation 5), which is defined net of both indirect taxes and intermediate input costs. This treatment is equivalent to writing out the full set of nested functions and their corresponding derivatives. The approach used here is simpler and has become traditional in many CGE models.[4]

The factor demand equations assume that primary factors (capital and labor) are paid the same *average* rental or wage (WF_f), regardless of sector. To capture the fact that in developing countries wage rates and returns to capital frequently differ across sectors, the model allows for distortions in factor markets. This is represented by a sector-specific parameter ($wfdist_{if}$) for each factor that measures the extent to which the sectoral marginal revenue product of the factor deviates from the average return across the economy. If there are no distortions in a particular factor market, this parameter equals one for all sectors.

The treatment of sectoral exports and imports follow closely the treatment in the 1-2-3 model. In Equation 11, total domestic production (X) is supplied to domestic (D) or foreign (E) markets. These three "goods" (X, D, and E) are all distinct, with separate prices, even though they have the same sectoral classification. Imports (M) and domestic goods (D) are also distinct from their composite (Q), with separate sectoral prices. The model allows two-way trade (that is, simultaneous exports and imports) at the sectoral level, again reflecting empirical realities in developing economies.[5]

One implication of this treatment of exports and imports is the partial insulation of the domestic price system from changes in world prices of sectoral substitutes. Through choice of substitution elasticities, the CET and CES functions provide a *continuum* of tradability at the sector level. This treatment is empirically more realistic than the extreme dichotomy between traded goods (where domestic and foreign products are perfect substitutes) and nontraded goods commonly found in analytic trade models. It also permits a richer speci-

Table 3: Income Equations

$$(16)\quad Y^F_f = \sum_i WF_f \cdot FDSC_{if} \cdot wfdist_{if}$$

$$(17)\quad Y^H_{cap\epsilon h} = Y^F_1 - DEPREC \qquad (Y^F_1 = capital\ factor\ income)$$

$$(18)\quad Y^H_{lab\epsilon h} = \sum_{f\neq 1} Y^F_f$$

$$(19)\quad TARIFF = \sum_i pw^m_i \cdot M_i \cdot t^m_i \cdot R$$

$$(20)\quad INDTAX = \sum_i P^x_i \cdot X_i \cdot t^x_i$$

$$(21)\quad HHTAX = \sum_h Y^H_h \cdot t^h_h \quad h = cap, lab$$

$$(22)\quad EXPSUB = \sum_i PW^e_i \cdot E_i \cdot t^e_i \cdot R$$

$$(23)\quad GR = TARIFF + INDTAX + HHTAX - EXPSUB$$

$$(24)\quad DEPREC = \sum_i depr^i \cdot P^k_i \cdot FDSC_{i1} \qquad (FDSC_{i1} = capital\ stock)$$

$$(25)\quad HHSAV = \sum_h Y^H_h \cdot (1 - t^H_h) \cdot mps_h$$

$$(26)\quad GOVSAV = GR - \sum_i P^q_i \cdot GD_i$$

$$(27)\quad SAVING = HHSAV + GOVSAV + DEPREC + FSAV \cdot R$$

fication of import demand than the two extremes of perfectly competitive and noncompetitive imports. Although flexible, the particular functional forms adopted here (CES and CET) do embody strong assumptions about separability and the absence of income effects. The ratios of exports and imports to domestic sales (E/D and M/D) at the sectoral level depend only on relative prices, and the demand for factor inputs in production does not depend on the export share.[6]

3.3. Income equations

Table 3 presents the equations that map the flow of income from value added to institutions and ultimately to households. These equations fill out the interinstitutional entries in the SAM. Many of the entries in this part of the SAM (and the income and expenditure flows they represent) will be specific to the structure of a particular economy. The distinction between parameters and variables also becomes important—although conceivably variable, many of these items will be set exogenously or determined by simple share or multiplier relationships, rather than through complex behavioral representations.

Equation 16 defines factor incomes, which in turn are distributed to capital and labor households in Equations 17 and 18.[7] Equations 19, 20, and 21 determine government tariff (TARIFF), indirect tax (INDTAX), and income tax (HHTAX) revenue, Equation 22 sums up sectoral export subsidies (EXPSUB), whereas total government revenue (GR) is obtained as their sum in Equation 23. The components of savings include financial depreciation (DEPREC) in Equation 24, household savings (HHSAV) from fixed savings propensities (mps) in Equation 25, and government savings (GOVSAV) in Equation 26, obtained as the difference between government revenue and consumption. Total savings (SAVING) in Equation 27 includes these three domestic elements plus foreign savings in domestic currency (FSAV · R).

Note that these income equations also embody the three major macro balances: savings-investment balance, the government deficit, and the current account. Firms and households save fixed proportions (depr and mps) of their incomes, government savings is the budget surplus or deficit, and foreign savings represents the capital inflow required to balance international payments, i.e., net foreign savings. Because the model satisfies Walras' Law, the three macro balances must satisfy the identity:

$$\textit{Private savings} + \textit{government savings} + \textit{foreign savings} = \textit{Investment}$$

The modeler must avoid the specification of independent equations for *each* of these components, because without some residual category, the resulting model will not satisfy Walras' Law and its solution will generally be infeasible. The range of alternative macro "closures" is discussed further.

Table 4: Expenditure Equations

(28) $P_i^q CD_i = \Sigma_h[\beta_{ih}^H \cdot Y_h^H \cdot (1 - mps_h) \cdot (1 - t_h^H)]$

(29) $GD_i = \beta_i^G \cdot gdtot$

(30) $DST_i = dstr_i \cdot X_i$

(31) $FXDINV = INVEST - \sum_i P_i^q \cdot DST_i$

(32) $P_i^k \cdot DK_i = kshr_i \cdot FXDINV$

(33) $ID_i = \sum_j b_{ij} \cdot DK_j$

(34) $GDPVA = \sum_i P_i^v \cdot X_i + INDTAX + TARIFF - EXPSUB$

(35) $RGDP = \sum_i (CD_i + GD_i + ID_i + DST_i + E_i - pw_i^m \cdot M_i \cdot R)$

3.4. Expenditure Equations

Table 4 provides equations that complete the circular flow in the economy, determining the demand for goods by the various actors. Private consumption (CD) is obtained in Equation 28 from summing household demands determined using fixed expenditure shares. In Equation 29, government demand (GD) for final goods is defined using fixed shares of aggregate real spending on goods and services (gdtot). Inventory demand (DST), or change in stocks, is determined in Equation 30 using fixed shares of sectoral production (dstr). Aggregate nominal fixed investment (FXDINV) is calculated in Equation 31 as total investment (INVEST) minus inventory accumulation. Aggregate fixed investment is converted into real sectoral investment by sector of destination (DK) in Equation 32 using fixed *nominal* shares (kshr), which sum to one over all sectors. Equation 33 translates investment by sector of destination into demand for capital goods by sector of origin (ID), using the capital composition matrix (b_{ij}).[8]

Equations 34 and 35 define nominal and real GDP, which are used to calculate the GDP deflator specified as the numeraire in the price equations. Real GDP (RGDP) is defined from the expenditure side, with imports valued in world prices (the world price times the exchange rate). In other words, the value of imports included in GDP *excludes* tariffs in the base year. Nominal GDP (GDPVA) is generated from the value-added side. Recall that value added prices (P^v) are calculated after subtracting intermediate input costs (valued at P^q), and that these intermediate input prices subtracted value imports *inclusive* of tariffs (because P^m is used). Thus, because tariffs have already been *subtracted* from value added, for expenditure and value added GDP to be comparable, these tariffs need to be *added back in* for the calculation of nominal GDP. Similarly, export subsidies have to be netted out. Nominal GDP

Table 5: Market Clearing Conditions and Macroeconomic Closure

$$(36) \quad Q_i = INT_i + CD_i + GD_i + ID_i + DST_i$$

$$(37) \quad \sum_i FDSC_{if} = fs_f$$

$$(38) \quad pw_i^m \cdot M_i = PW_i^e \cdot E_i + FSAV$$

$$(39) \quad SAVING = INVEST$$

in Equation 34 is thus the sum of nominal value added, indirect taxes, and tariffs, and net of export subsidies. Similarly, export subsidies have to be netted out.

3.5. Market Clearing Conditions and Macroeconomic Closure

Table 5 contains equations defining the system constraints that the model economy must satisfy. Although recognizing that the model is a general equilibrium system, with all endogenous variables jointly determined, it is nevertheless useful to think in terms of matching each of these equilibrium conditions with an "equilibrating variable." In a competitive market economy, these equilibrium conditions correspond to market-clearing conditions, with prices adjusting to clear each market.

Equation 36 states that the sectoral supply of composite commodities must equal demand, and thus defines market-clearing equilibrium in the product markets. There is also an analogous sectoral market-clearing equation for domestically produced goods sold on the domestic market (D). However, from Equation 15 it is evident that the ratio of imports to domestic sales is the same for all categories of imports. Thus, at the sectoral level, specifying a separate market-clearing condition for domestically produced goods sold on the domestic market amounts to multiplying through both sides of Equation 36 by the ratio D_i/Q_i. Since, if Equation 36 holds, so will this new equation in which both sides are multiplied by the same number, no separate equation is required.[9]

The equilibrating variables for Equation 36 are sectoral prices. There are nine prices in the model that have sectoral subscripts: pw^m, PW^e, P^m, P^e, P^q, P^x, P^v, P^d, and P^k. The world prices (pw^m and PW^e) are treated separately. Of the remaining seven, six appear on the left hand side of price equations, leaving P^d as the variable "free" to adjust.

Equation 37 defines equilibrium in factor markets. The supplies of primary factors (fs_f) are fixed exogenously. Market clearing requires that total factor demand equal supply, and the equilibrating variables are the average factor prices (WF_f). In the model specified here, all primary factors are intersectorally mobile: factor demands are determined through Equation 9, market clearing is achieved via changing factor prices (WF_f) together with exogenous sectoral-specific parameters ($wfdist_{if}$). In empirical applications for developing countries; however, it is common to assume that sectoral capital stocks are fixed exogenously. Fixing capital stocks means that the factor demands ($FDSC_{i1}$) of Equation 9 are fixed, so that aggregate supply and demand for capital are automatically equal, and the market clearing condition for capital in Equation 37 is redundant and can be dropped. Without factor mobility, however, sectoral rental rates will not be the same across sectors, nor can they be made to conform to some initial pattern of distortions embodied in the $wfdist_{i1}$ parameters. Thus, with fixed capital stocks, the wfdist parameters become endogenous.[10]

The remaining two equations describe macroeconomic equilibrium conditions for the balance of payments and savings-investment balance. Satisfying each of these requires the modeler to select the variables that will adjust freely to achieve equilibrium and constrain other variables by fixing them exogenously. In Equation 38, the balance of payments is represented in the simplest conceivable form: foreign savings (FSAV) is the difference between total imports and total exports. With foreign savings set exogenously, the equilibrating variable for this equation is the exchange rate (R). Equilibrium will be achieved through movements in R that affect export and import prices (P^m and P^e) relative to domestic good prices (P^d)—in other words, by changing the relative price of tradables to nontradables. For example, an increase in the exchange rate leads to a real depreciation, so that tradable prices (P^m and P^e) rise relative to P^d. Given the export supply and import demand functions, the result will be higher exports and lower imports. Thus, from an initial equilibrium, any fall in foreign savings will lead to a new equilibrium with a higher (depreciated) exchange rate.[11]

Alternative foreign exchange market closure choices are also possible. For example, the exchange rate can be fixed, and foreign savings can adjust. Alternatively, the price index (PINDEX) can be fixed exogenously, with both R and FSAV determined endogenously. In fact, what the model determines is a stable relationship between the *real* exchange rate and the balance of trade. A macro model of this type can be used to determine only one of the following variables: the nominal exchange rate (R), the price level (PINDEX), or balance of trade (FSAV).

The final macro closure condition in Equation 39 requires that aggregate savings equal aggregate investment. The components of total savings have already been discussed: government savings is determined as the residual after government revenue is spent on fixed real government consumption (gdtot), private savings are determined by fixed savings rates, and foreign savings (in at least one closure choice) are fixed exogenously. This model specification corresponds to a "savings-driven" model, in which aggregate investment is the endogenous sum of the separate savings components. This is often called "neoclassical" closure in the CGE literature.

As with the balance of payments equation, there are alternative ways to achieve savings-investment equilibrium in CGE models. Various "investment driven" closures have been used in which aggregate investment (INVEST) is fixed and some savings component or parameter (such as mps or even FSAV) becomes endogenous. "Keynesian" closures, which incorporate multiplier mechanisms, are possible as well.[12]

After macro closure decisions are made, careful counting of the equations and variables in the model indicates that the number of equations is one more than the number of endogenous variables. However, the core CGE model satisfies Walras' Law. Therefore, the equations defining the equilibrium conditions (Tables 3–5) are not all independent; any one of them can be dropped, thus equating the number of variables and equations. In practice, the savings-investment equation is most frequently dropped, although the choice has no effect on the solution of the model.

4. Implementing the CGE model in GAMS

The discussion of the core CGE model has concentrated on a description of the theoretical and analytical basis for the model—that is, the equations and their derivation and interpretation. The purpose of the current section is to move beyond this abstract treatment to a consideration of the steps required to implement such a CGE model.

The example we use is a CGE model of Cameroon. A middle-income African country, Cameroon has structural features that make it a typical developing country, and a good candidate for illustrating the implementation process. Almost 70% of the population is employed in agriculture. Traditionally, the country has relied on cash crops—coffee and cocoa—for its foreign exchange. More recently, it has become an oil exporter. In fact, the Cameroon model was built to study the effect of oil revenues on the economy. The government depends on indirect taxes—production taxes and import tariffs—for the majority of its revenues. As a member of the CFA Franc Zone, Cameroon's nominal exchange rate is fixed with respect to the French franc. This exchange rate regime brings out the issues of the real exchange rate—the relative price of tradables to nontradables—in sharp relief. Even though the nominal exchange rate remains unchanged, Cameroon (both the country and the model) can experience movements in the real exchange rate in response to changing external conditions. These movements in turn permit some important insights into the nature of the "Dutch disease" in developing countries.[13]

4.1. GAMS: An introduction and overview

The individual pieces of the CGE model combine to form a complex set of simultaneous nonlinear equations. Solution of such equation systems is a difficult computational problem that in the past has limited the application of such models. Modelers often had to tailor the model's structure to a particular solution method, and frequently devoted as much time (or more) to grappling with solution algorithms on mainframe computers as was spent in pursuit of economic insights.

In recent years, however, two developments have changed this situation. First, the increasing power and availability of personal computers allows every modeler to have desktop access to computational resources that were once available only on mainframe computers. Second, the development of packaged software to solve complex mathematical or statistical problems such as that posed by our CGE model has permitted modelers to return their attention to economics. The CGE model presented here has been developed and solved using one such package, called the General Algebraic Modeling System (or GAMS).[14] GAMS is designed to make complex mathematical models easier to construct and understand. While used here for solving fully determined, nonlinear CGE models, where the number of equations equals the number of variables, GAMS is also suitable for solving linear or nonlinear, nonlinear, and mixed-integer programming problems. A major virtue of GAMS is that models are specified in (nearly) standard algebraic notation. Table 6 summarizes the rules of syntax used in GAMS.

Table 7 summarizes the components that are required to identify and run CGE model on GAMS. Although some variation on the sequence or contents of these components is possible, the general pattern is common to most models prepared with GAMS. In the SETS section, all of the indices to be used in the model (including sectors, factors of production, household types, and for dynamic simulations, periods) must be identified, and any subsets of these indices (tradable and nontradable sectors) identified. The PARAMETERS and INPUT DATA sections include model parameters such as the input-output figure, elasticities and coefficients for production, CES import and CET export functions, and tax rates. Also included in these sections are initial data for most of the variables in the model, entered into dummy scalars, vectors, and matrices to be used subsequently to initialize the GAMS variables.

The CALIBRATION section calculates any parameters not already provided to the model. Because the initial data have been provided in the previous section, this is also where subsets dependent on characteristics of the data (such as traded or nontraded classifications) are defined. (See the next section for further discussion of model calibration.) The VARIABLES section lists the variables that appear in the model and their associated indexes, whereas the EQUATION NAMES sections does the same for model equations. The EQUATIONS section provides the heart of the GAMS program, containing algebraic representation of all equations of the model. The INITIAL VALUES section transfers the initial data to the variables from the parameters and figures where it was entered earlier. The CLOSURE section allows for choice among alternative macro closures or other model features. Finally, the SOLVE AND DISPLAY section defines the model by giving it a name, specifying the list of equations to be used, providing other solution options, telling GAMS to solve the model, and displaying the results in one or more figures.

4.2. CGE model equations in GAMS

The preceding discussion of the structure and syntax of GAMS provides a brief introduction to model specification in GAMS. For now, we concentrate our attention on the equation specification, and examine how the equations of the multisector model presented in algebraic form in Section 3 are translated into GAMS equations. The close resemblance between GAMS syntax and standard algebra will make this fairly straightforward in most instances, but there are enough divergences to make a careful comparison helpful.

Table 8 contains the GAMS version of the price equations. These translate almost exactly from the earlier version in Table 1. The equation defining domestic import prices (PMDEF) is specified only over the index IM, not I. IM(i) and IMN(i) are subsets of I, defined by: *IM(i) = YES$M0(i)* and IMN(i) = NOT IM(i).

IM(i) thus corresponds to traded import sectors (defined as sectors where imports are initially non-zero), whereas IMN(i) is the set of all other nonimported sectors. An equivalent index (IE) is used in the equation defining domestic export prices (PEDEF).[15] The use of the

Table 6
Syntax rules in GAMS

Information	Description	Examples
Data:		
Parameters	Scalar, vector, or array of data that remains constant in the GAMS program	For scalars by assignment: ER0 = 1.0; For scalars with definition: SCALAR ER0 REAL EXCHANGE RATE/1/; For vectors or arrays by assignment: BETA(i) = 1.0; For arrays in tabular form: TABLE WL0(f, i) WAGES BY CATEGORY & SECTOR DOMESTIC EXPORT UNSKILL 55.9 91.3 SKILL 212.5 34.0
Variables	Scalar, vector, or array of data in the model that can vary as part of the GAMS program	Each Variable (either scalar, vector, or array) has different values that can be set by using different suffixes: X.L = 10; The Level or current value of X X.LO = .1; The LOwer value of X X.UP = 100; The UPper bound of X X.FX = 10; The FiXed value for X X.FX is equivalent to X.L = X.LO = X.UP = 10, and has the effect of making X into a fixed parameter
Operators:		
Algebraic	Standard algebraic operators (−, +, *, / and **) for subtraction, addition, multiplication, division, and exponentiation. Special operator ($) for performing operations conditional on certain information (by default, test is whether expression is non-zero).	Standard operators: X = (((A + B − C)*D)/E)**F; Special operator: RHO(i)$SIG(I) = (1 − SIG(i)) − 1; Sets RHO(i) equal to 1/SIG(i) − 1 only if SIG(i) is non-zero
Relational	Standard relational algebraic operators in character form (LT, LE, EQ, NE, GE, GT) and inclusive /−exclusive operators (AND, OR, NOT).	Relational operator with $: SIG(i)(RHO(i)NE − 1) = 1/(1 + RHO(i)); Calculates SIG(i) only if RHO(i) does not equal negative 1 Relational NOT operator: S(i) = V(i)$(NOT V(i) GT 4) Set S(i) equal to V(i) for all cases where V(i) is not greater than 4.
Functional	Additive and multiplicative summation functions in character from (SUM, PROD)	Additive summation: TOTAL = SUM(i, X(i)); Sums X(i) over all i and places result in parameter called TOTAL. Multiplicative summation: TOTAL = PROD(j$(X(j) NE 0), X(j)); Multiples together all non-zero elements in X(j) and places results in parameter TOTAL.
Equations:		
Constraints	In model equations, type of constraint (greater than, less than, or equality) specified by placing letter between two equal signs (= G =, = L =, = E =).	In most CGE models, all equations are strict equalities: PM(i) = E = PWM(i)*(1 + TM(i))*R;

Table 7
Components of a CGE model in GAMS

Component	Description	Sample Section
Sets	Declares all sets (e.g., sectoral and household indexes) used in the model, add (optionally) defines subsets from these sets. The SET command specifies an index, an index name, and a list of elements, including a 10-character label and a longer description. The ALIAS command establishes that I and J can be used interchangeably as indices, Individual elements are referenced by the label in quotes ("ag − exp + ind).	SET i SECTORS / food + for Food & Forest Crops cashcrop Cash Crops food + con Food Proc & Cons Gds intergds Inter & Const Gds cap + cons Capital Gds & Const services Pub & Priv Services / f FACTORS/capital, rural unskill, skilled/; ALIAS (i, j); IM(i) TRADED IMPORT SECTORS; IM(i) identifies a subset of I; the subset is created in the CALIBRATION section.
Parameters	A constant or group of constants that may be a scalar, vector, or matrix of two or more dimensions. Initialize using assignment statements, lists, or TABLE format (for matrices). Parameters are identified with a 10- character label and an optional description. Dummy parameters are often used here to enter the initial values of variables used in the model; one common convention is to identify such variables with a suffix zero.	Parameter TE(i) Export Subsidy Rates TE(i) =.10; TE("cashcrop") = 0.20; Declares parameter, then initialize all elements using assignment statement, and then set one particular element to a different value. Parameter TE(i) Export Subsidy Rates / .10 .20 .10 .10 · · · .10 / ; Declaration followed by list initialization in a single statement. Parameter M0(i) Initial Volume of Imports; Dummy vector parameter to hold initial values.
Input data	Parameter data not already initialized via the list option as well as base period data for the model. TABLE commands are used for multidimension parameters or for dummy tables that contain base data which is later used to initialize the variables.	Scalar ER0 Initial Exchange Rate /.21/; Table IO(i, j) Input-output Coefficients food + for cashcrop food + con · · food + for .02796 .11666· · cashcrop .01516 .01469 · · · · · ;
Calibration	Calculate any parameters (such as allocation shares, or production function constants) not yet provided, and re-calculate parameters or initial values to avoid rounding problems. Goal is to insure that date provided to GAMS will automatically satisfy all equations in the base period.	Alpha(i, f) = (WDIST(i, f)*WF0(f)*FDSC0(i, f)) /(PVA0(i)*XD0(i)); Recalculate Cobb-Douglas production function exponent for sectoral labor demand of each type,using parameter values already provided. IM(i) =YES$M0(i); Defines the subset IM as containing all sectors for which base year imports (M0) are non-zero.

(continued on next page)

Table 7 *(continued)*

Component	Description	Sample Section
Variables	List of all variables that appear in the model, identified with 10-character label and optional description. List can include variables that are fixed in a particular experiment because of macro closure or other specification choice.	Variables PD(i) domestic prices PM(i) domestic price of imports; PM.LO(im) = .01; PD.LO(i) =.01; These statements establish lower bounds to avoid numeric singularities if prices are zero or negative during the solution process.
Equation names	List of all equations and index over which they are defined. Equations are identified with 10-character label and optional description.	PMDEF(i) domestic import price definition PEDEF(i) domestic export price definition
Equations	Algebraic representation of equations in CGE model. Syntax is equation name, followed by two dots, followed by equation.	PMDEF(im) . . PM(im) = E = WM(im)*EXR*(1 + TM(im)); PEDEF(ie) = E = PWE(ie)*EXR*(1 + TE(ie));
Initial values	Provide initial point for GAMS to start from, using actual values or dummy parameters created earlier.	M.L(i) = MO(i); Assignment statement sets current (initial) value of M equal to M0.
Closure	Fix variables as part of macro closure choices.	EXR.FX = EXR.L; Fix EXR by setting upper and lower bounds equal to current value (see Figure 6 for syntax)
Solve and display	MODEL command names model (CAMCGE) with a description, and identifies equations (ALL). SOLVE command tells GAMS to solve model by maximizing function called OMEGA. DISPLAY allows for display of model results.	Options ITERLIM = 1000, LIMROW = 0, LIMCOL = 0; Model CAMCGE SQUARE BASE MODEL ALL; Solve CAMCGE MAXIMIZING OMEGA USING NLP; Display EXR.L, PM.L, PE.L;

$ operator in the ABSORPTION and SALES equations defining PQ and PX ensures that the import and export prices are added to the domestic price only when the sector is traded, i.e. it belongs to the subset IM(i) or IE(i). ACTP determines the value added or net price, whereas PKDEF and PINDEXDEF define the sectoral capital goods price and *numeraire*, respectively.[16]

Table 9 contains the quantity equations corresponding to the earlier presentation in Table 2. The production function in the ACTIVITY equation shows the Cobb-Douglas aggregation of capital and labor of different types (recall that capital is the first element in the set f of primary factors). The adding up constraint required of Cobb-Douglas function exponents means that the alpha parameters summed over all factors (the set f) equal 1 for each sector. The first-order conditions of PROFITMAX contain the wfdist parameter to allow for intersectoral divergences from the average wage for each labor type. Note that this first-order

Table 8
GAMS price equations

(1)	PMDEF (im) . .	PM(im) = E = pwm(im)*EXR*(1 + tm(im));
(2)	PEDEF (ie) . .	PE(ie) = E = PWE(ie)*EXR*(1 + te(ie));
(3)	ABSORPTION(i) . .	PQ(i)*Q(i) = E = PD(i)*D(i) + (PM(i)*M(i))$im(i);
(4)	SALES(i) . .	PX(i)*X(i) = E = PD(i)*D(i) + (PE(i)*E(i))$ie(i);
(5)	ACTP(i) . .	PX(i)*(1 − tx(i)) = E = PV(i) + SUM(j, a(j, i)*PQ(j));
(6)	PKDEF(i) . .	PK(i) = E = SUM(j, PQ(j)*b(j, i));
(7)	PINDEXDEF . .	PINDEX = E = GDPVA/RGDP;

condition is defined over sectors (index i) and primary factors (index f), and thereby embodies the assumption that capital is mobile among sectors.[17]

The ARMINGTON (CES) composite demand equation and CET export supply equation are defined only over the relevant traded goods (im and ie); the subsequent two equations (ARMINGTON2 and CET2) require that, for nontraded sectors, IEM and IEN, total domestic production equal domestic demand. The first-order conditions determining import demand (COSTMIN) and export supply and demand (ESUPPLY and EDEMAND) are as previously presented. They are defined only for traded sectors; exports and imports are fixed at zero for nontraded sectors by assignments in the CLOSURE section of the GAMS model (see Table 12). Note that the export demand function (EDEMAND) is defined over a *different* export index (ied), which contains sectors selected by the modeler for which Cameroon is assumed to have downward sloping world demand curves, reflecting its market power in these products.

Table 10 contains the income equations presented in Table 3. The equations are all quite similar in their appearance to the earlier algebraic representations. Income for each production factor (YFDEF) is the sum across sectors of each factor share. The household income equations (YHKDEF and YHLDEF) illustrate the use of individual set elements ("capital" and "labor" in quotes) rather than whole sets.

Table 11 contains the expenditure equations of Table 4. The equations are all the same as

Table 9
Quantity equations

(8)	ACTIVITY(i) . .	X(i) = E = AD(i)*PROD(f$alpha(i, f), FDSC(i, f)**alpha(i, f));
(9)	PROFITMAX(i, f)$wfdist(i, f) . .	WA(f)*wfdist(i, f)*FDSC(i, f) = E = X(i)*PV(i)*alpha(i, f);
(10)	INTEQ(i) . .	INT(i) = E = SUM(j, a(i, j)*X(j));
(11)	CET(ie) . .	X(ie) = E = AT(ie)*(gamma(ie)*E(ie)**rhot(ie) + (1 − gamma(ie))*D(ie)**rhot(ie))**(1/rhot(ie));
	CET2(ien) . .	D(ien) = E = X(ien);
(12)	ESUPPLY(ie) . .	E(ie)/X(ie) = E = ((PE(ie)/PD(ie))*((1 − gamma(ie))/ gamma(ie)))**(1/(rhot(ie) − 1));
(13)	EDEMAND(ied) . .	E(ied) = E = econ(ied)*(pwe0(ied)/PWE(ied))**eta(ied);
(14)	ARMINGTON(im) . .	Q(im) = E = AC(im)*(delta(im)*M(im)**(−rhoc(im)) + (1 − delta(im))*D(im)**(−rhoc(im)))**(−1/rhoc(im));
	ARMINGTON2(iem) . .	Q(iem) = E = D(iem);
(15)	COSTMIN(im) . .	M(im)/D(im) = E = ((PD(im)/PM(im))*(delta(im)/ (1 − delta(im))))**(1/(1 + rhoc(im)));

Table 10
Income equations

(16)	YFDEF(f) . .	YF(f) = E = SUM(i, WF(f)*wfdist(i, f)*FDSC(i, f));
(17)	YHKDEF . .	YH(“capital”) = E = YF(“capital”) − DEPREC;
(18)	YHLDEF . .	YH(“labor”) = E = SUM(f, YF(f)) − YF(“capital”);
(19)	TARIFFDEF . .	TARIFF = E = SUM(im, tm(im)*M(im)*pwm(im))*EXR;
(20)	INDTAXDEF . .	INDTAX = E = SUM(i, tx(i)*PX(i)*X(i));
(21)	HHTAXDEF . .	HHTAX = E = SUM(h, th(h)*YH(h));
(22)	EXPSUBDEF . .	EXPSUB = E = SUM(ie, te(ie)*E(ie)*PWE(ie))*EXR;
(23)	GREQ . .	GR = E = TARIFF + INDTAX + HHTAX − EXPSUB;
(24)	DEPREQ . .	DEPREC = E = SUM(i, DEPR(i)*PK(i)*FDSC(i, “capital”));
(25)	HHSAVEQ . .	HHSAV = E = SUM(h, YH(h)*(1 − th(h))*mps(h);
(26)	GRUSE . .	GR = E = SUM(i, P(i)*GD(i)) + GOVSAV;
(27)	TOTSAV . .	SAVING = E = HHSAV + GOVSAV + DEPREC + FSAV*EXR;

those specified in the earlier figure. Finally, Table 12 shows the specification of market-clearing conditions used in the Cameroon model. These equations are equivalent to those presented in Table 5. Because the model satisfies Walras’ Law, these equations are functionally dependent and any one of them can be dropped. Rather than drop an equation, it is convenient to add a slack variable, WALRAS1, to the equation which would otherwise be dropped—in this case, the savings-investment equilibrium equation (the WALRAS equation). In equilibrium, the value of the WALRAS1 variable must be zero. If the model SAM balances, with all agents on their budget constraints, the WALRAS1 variable should also equal zero out of equilibrium as well. Checking it is a good test of model consistency.

The final function listed (OBJ) serves a special purpose in GAMS. GAMS is designed as a general purpose programming package that can be used to solve a variety of linear, nonlinear, or mixed integer optimization problems in which the objective function plays an important role. For this reason, GAMS *requires* that an objective variable be specified (here called OMEGA) and included in an objective function (defined here as a Cobb-Douglas utility function over labor household consumption). However, in a fully determined (or “square”) model such as ours, where the number of endogenous variables equals the number of constraints, the model will have a unique solution, so that no optimization of the objective can occur once a feasible solution is identified.

The final few lines shown in Table 12 help define the model “closure.” Several items have

Table 11
Expenditure equations

(28)	CDEQ(i) . .	PQ(i)*CD(i) = E = SUM(h, YH(h)*(1 − th(h))*(1 − mps(h))*cles(i, h));
(29)	GDEQ(i) . .	GD(i) = E = gles(i)*GDTOT;
(30)	DSTEQ(i) . .	DST(i) = E = dstr(i)*X(i);
(31)	FIXEDINV . .	FXDINV = E = INVEST − SUM(i, DST(i)*PQ(i));
(32)	IEQ(i) . .	ID(i) = E = SUM(j, b(i, j)*DK(j));
(33)	PRODINV(i) . .	PK(i)*DK(i) = E = kshr(i)*FXDINV;
(34)	GDPY . .	GDPVA = E = SUM(i, PV(i)*X(i)) + INDTAX + TARIFF;
(35)	GDPR . .	RGDP = E = SUM(i, CD(i) + GD(i) + ID(i) + DST(i)) + SUM(ie, E(ie)) − SUM(im, pw0(im)*M(im)*EXR);

Table 12
Market clearing conditions

(36)	EQUIL(i) . .	Q(i) = E = INT(i) + CD(i) + GD(i) + ID(i) + DST(i);
(37)	FMEQUIL(f) . .	SUM(i, FDSC(i, f)) = E = fs(f);
(38)	CAEQ . .	SUM(im, pwm(im)*M(im)) = E = SUM(ie, PWE(ie)*E(ie)) + FSAV;
(39)	WALRAS . .	SAVING = E = INVEST;
(40)	OBJ . .	OMEGA = E = PROD(I$CLES(i, “labor”), CD(i)**CLES(i, “labor”));
		M.FX(imn) = 0; E.FX(ien) = 0;
		FDSC.FX(i, f)$(WFDIST0(i, f)EQ 0) = 0;
		FSAV.FX = FSAV0;
		EXR.FX = EXR0;

already been mentioned: exports and imports in nontraded sectors are fixed at zero. Factor demand in sectors not already using that factor are fixed at zero by testing whether the corresponding wfdist value is zero as well. The other variables shown are made exogenous to close the model, reflecting the fact that at present, there are more variables (upper case names) than equations.[18] Cameroon’s nominal exchange rate is fixed because of its participation in the CFA zone, so that EXR is fixed in the model. Foreign savings (FSAV) is assumed fixed as well, so that the major macro adjustment channel will be through changes in the price level (PINDEX).[19]

5. Calibration of the model

The previous section translates the equations of the analytic CGE model into GAMS. Thanks to the close relationship between GAMS syntax and standard algebraic syntax, the task was relatively straightforward. However, nothing has been said thus far about the other translation that must be performed: from the data in the SAM (and elsewhere) into the parameters and initial values in GAMS.

The equations that need to be specified empirically range from the single parameter equations of the income and expenditure blocks to the two-parameter Cobb-Douglas production functions and three-parameter CET export supply and CES import demand relationships. To estimate this full set of parameters econometrically would be a daunting task, even if adequate data series were available. However, the required time-series or cross-sectional data rarely, if ever, exist; as a result, the approach adopted here (and in nearly all CGE applications) is to parameterize the model using information contained in the SAM, supplemented as needed by additional sources or, when possible, by econometric estimates.

The SAM provides a snapshot of the economy at a single point in time. As outlined earlier, it documents the income and outflow (in value terms) in each and every market and account. Each row provides information on the income to an account, whereas the corresponding column portrays the outflow, and the row sum and column sum must balance. For the SAM, this balance implies: (1) costs (including distributed earnings) exhaust revenues for producers; (2) expenditure (plus taxes and savings) equals income for each actor in the model; and (3) demand equals supply of each commodity. Note that these conditions are the same as those associated with equilibrium in the CGE model. Calibration of the model involves determining a set of parameters and exogenous variables so that the CGE model solution exactly replicates the economy represented in the SAM.

5.1. Factor income proportionality constants

The SAM includes the value data on revenue flows that are needed to determine the parameters of the income/expenditure block of equations. First is the wfdist parameter in that block, which relates sector-specific factor returns to the economywide average factor return (WF). The SAM includes data on factor payments by factor and sector; coupled with data on the sectoral *quantity* of each factor (workers, capital stock), both the sector-specific (wfdist) and economywide average (WF) factor returns can be calculated. For example, the sector-specific wage for unskilled labor equals a sector's "wage bill" for the labor category divided by the number of workers employed. The average unskilled wage is the economywide unskilled wage bill divided by the total number of unskilled workers employed. The wfdist parameter for each sector is the ratio of the sector specific to the average unskilled wage.

Capital returns by sector can be determined residually given data on value added and wages. Once estimates of sectoral capital stocks are provided (no easy task in most developing countries), sectoral capital rental rates can be calculated, and wfdist parameters can be obtained in the same way as for labor. If no data on sectoral capital stocks can be provided, the modeler can instead provide estimates of sectoral rental rates (including as an extreme case the neoclassical assumption of uniform sectoral rental rates) and calculate the capital stock inputs residually.[20]

The wfdist parameters that emerge from this calibration reflect: (1) distortions in the factor markets, such as impediments to factor mobility among sectors or differential tax rates; and (2) aggregation limitations or errors in the definition of factors. Examples of this second effect might be variations in capital vintages across sectors that are not captured in capital stock data, or variations in the age, skill, or education composition of the labor force across sectors. The CGE model assumes that sectoral returns to a given factor would be equal if the factors were indeed homogeneous and there were no rigidities or distortions.

The existence of such rigidities and distortions is reflected in the fact that the measured wfdist parameters differ from one. Moreover, by assuming that the wfdist parameters remain constant, the modeler assumes that the structural characteristics responsible for these differentials are invariant to the question at hand. That is, the CGE policy experiments must be seen as comparing second-best situations, with existing factor-market distortions assumed to be captured by the parameters. Indeed, the existence of these distortions and the CGE model's capacity to incorporate them and generate quantitative outcomes is a strong argument for using CGE models. With theoretical or analytic models, welfare comparisons in second-best circumstances are mostly ambiguous, as their outcomes depend on parameter values. Of course, simulations in which the wfdist parameters change, either exogenously or endogenously, are also possible, to analyze the effect that reducing (or increasing) distortions will have on the economy.

5.2. Tax and savings rates

The next set of parameters to be determined include the institutional tax and savings rates. The SAM data provides the values of total household income, and the amounts saved and paid in taxes. The average tax and savings rates for each institution are simply calculated as the ratio of taxes or savings to total income. The mapping from factor income to households (or allocation matrix in the SAM) is quite simple in the Cameroon model, with only two household types. The model distinguishes households along functional lines, with "labor" and "capitalist" households, the former receiving all labor factor income, the latter all capital income. More complex schemes can be adopted; however, as long as the household types appear in a SAM, then the tax and savings rates (and government transfers, foreign remittances, or other flows) are easily parameterized for use in the GAMS model.

5.3. Sectoral composition shares

There are a number of parameters that determine the sectoral composition of various categories of demand, including:

- demand for intermediate inputs (a_{ij})
- composition of investment and capital goods (b_{ij})
- household consumption ($cles_{ih}$)
- government final demand ($gles_i$)
- investment allocation by sector of destination ($kshr_i$)

Given strong assumptions about functional forms, all of these parameters can be computed from SAM data. Depending on functional choices, the parameters can refer to real or nominal magnitudes.

In the core CGE model (and its implementation for Cameroon), intermediate goods are demanded in fixed proportions (the a_{ij} coefficients) defined in real terms (physical units of input per unit of output). Note that intermediate demand is for the composite good, which is a CES aggregation of imported and domestic goods. Thus the input-output matrix required corresponds to the usual "total" (domestic plus imported) fixed coefficients matrix of input-output analysis. The elements of the capital composition matrix (b_{ij}) are also defined in real terms, as units of composite (domestic plus imported) good from sector i required to create one unit of capital in sector j. Given the frequent absence or poor quality of data on sectoral aggregate capital stocks in many developing countries, obtaining or estimating the capital coefficients matrix that describes the *composition* of capital is often difficult. Such information is by no means crucial; if information on the sectoral composition of capital is not available, the modeler can assume that capital investment in all sectors has the same structure as average investment, which is contained in the investment final demand column. By choosing this simplification, the modeler is eliminating the possibility of affecting the pattern of final demand in the static CGE model through investment allocation—the allocation pattern does not matter, because all capital goods have the same composition.

The household consumption demands ($cles_{ih}$) are defined as expenditure shares—the fraction of each household's total expenditure that is spent on good i. This formulation is consistent with an underlying Cobb-Douglas utility function for each household, which will yield fixed sectoral expenditure shares. The government's consumption demands ($gles_i$) are defined in real terms, because total government expenditure is defined as a real variable. For a given real consumption level (gdtot), the government's nominal consumption expenditure will thus depend on the sectoral shares and the prices of each commodity in the consumption bundle. Finally, the allocation of investment by sector of destination is given by fixed nominal shares ($kshr_i$).[21]

5.4. Production and trade aggregation functions

Identifying the parameters of the production and trade aggregation functions involves accounting for real flows, nominal flows, and the first-order conditions of cost minimization or profit maximization. Incorporating these conditions in the model imposes constraints on possible parameter values analogous to identification conditions common in simultaneous estimation of econometric models. The calibration procedure followed here uses these conditions, coupled with exogenous estimates of certain parameters, to compute all other parameters so that all the production and trade equations in the model are satisfied using the price and quantity data taken from the base period SAM. Because there is only one observation for each parameter being estimated, this process should not be confused with statistical estimation. Model calibration is a *mathematical* procedure, not a *statistical* one.

Common practice in calibrating CGE models is to assume that the base year of the model is also the base year for all price indices. For convenience, all physical units are defined so that prices equal one, which also implies that sectoral flows in the SAM measure both real and nominal magnitudes. Thus, the initial goods market equilibrium between supply and demand that occurs when the CGE model is first solved will occur at product prices equal to one. Such choice of units simplified calibration and interpretation of results, but it is not required.[22]

The main trick to calibration of production and trade function parameters is to solve the model equations in reverse: *given* specific (initial) values for all of the variables, solve for the parameters. For example, the Cobb-Douglas production functions in the Cameroon model each have five unknown parameters: the four factor share parameters (alpha), corresponding to three labor inputs and capital, and the shift parameter (AD). From the SAM we get data on wages (WF), output (X), factor inputs (FDSC), and the calculated factor differentials (wfdist) and value added prices (PV). These data suffice to identify the unknown parameters. In the first-order conditions for profit maximization (using the GAMS version),

$$WF(f)*wfdist(i,f)*FDSC(i,f) = E = X(i)*PV(i)*alpha(i,f)$$

only the share parameters are unknown:

$$alpha(i,f) = [WF(f)*wfdist(i,f)*FDSC(i,f)]/X(i)*PV(i)$$

Thus the shares can be solved for directly: Given that the data from the SAM add up, total factor payments equal total value added in each sector. This in turn implies constant returns to scale or, equivalently, that the sum of the alpha parameters for each sector is one. The alpha share parameter for the capital input is usually obtained as one minus the sum of the labor shares.[23]

Once the factor shares are determined, only the shift parameter remains to be calibrated. Given that we have data on factor inputs, share parameters and output, solving for AD is straightforward:

$$AD(i) = X(i)/(\mathrm{PROD(f, FDSC(i, f)^{**}alpha(i, f))})$$

Calibration of the CES and CET trade aggregation functions follows the same approach. CES and CET functions are characterized by an elasticity of substitution (different from one), share parameters (that sum to one), and a shift term. Unlike the Cobb-Douglas function, available equations from the CGE model fall short (by one) of identifying all of these parameters. Standard practice is for the modeler to specify the elasticity (of substitution or transformation) outside the model, based (when possible) on econometric estimates.

For the CES function, the elasticity of substitution measures the degree to which imported and domestic versions of the same commodity can be substituted for one another in demand. Once the sectoral elasticities (sigc) are provided, algebraic manipulation of the model equations together with the data on imports (M), domestic demand (D), and base period prices (PM and PD) are sufficient to allow solution for the share parameters (delta). Starting from the import demand function (COSTMIN):

$$M(im) = D(im)^*((PD(im)/PM(im))^*(delta(im)/1 - delta(im))))^{**}(1/(1 + rhoc(im)))$$

Calculate rhoc from the elasticities provided, and solve for delta:

$$rhoc(im) = (1/sigc(im)) - 1$$

$$xxxx(im) = (PM(im)/PD(im))^*((M(im)/D(im))^{**}(1 + rhoc(im)))$$

$$delta(im) = xxxx(im)/(1 + xxxx(im))$$

Finally, the shift parameter can be calculated from the ARMINGTON function:

$$ac(im) = Q(im)/(delta(im)^*M(im)^{**}(rhoc(im)) + (1delta(im))^*D(im)^{**}(rhoc(im)))^{**}(1/rhoc(im))$$

Computation for the export supply function is similar.

5.5. Running, debugging, and changing the model

Once the calibration procedure is completed, the general equilibrium model is computable. If the model specification and data calibration are correct, then the data provided to GAMS together with the CGE model equations will be a solution to the model—in other words, what comes out is the same as what goes in.

When constructing a new model, or modifying an existing one, quite often what comes out initially is not the same as what went in. There are three basic consistency checks that must be passed, and provide clues to where errors occur. First, because the model is fully determined, with nothing calculated as a residual, there should be no “leakages” in the system. Determining whether a leakage is occurring is easy. Check the WALRAS1 slack variable in the savings-investment equilibrium condition. If it equals zero, then there is no leak and the model is closed. If this equation is not satisfied, so that WALRAS1 does not equal zero, then there is a problem. The model SAM will not balance, and there is an error somewhere in the system of equations.

The second test for consistency (which should follow the first) is to check if the original data fed into the model are identified as a solution by GAMS. The task of GAMS is to find a vector of prices, wages, and an exchange rate that satisfy a complex set of nonlinear equations. If the prices, wages, and exchange rate are unchanged after GAMS has run, then the original data represented a solution; if they have changed (and therefore other variables as well), then the calibration procedure outlined earlier was not successful, or the data provided did not come from a consistent, balanced SAM. This second case can occur quite frequently when trying to combine data from different periods or sources into a consistent starting point. The challenge here is to identify the equations in which problems are occurring, and recalibrate as required to eliminate the problem.[24]

The third consistency test stems from the fact that the CGE model in its entirety is homogeneous of degree zero, so that doubling all prices should leave all *real* variables unchanged. In practical terms, this check is easy to perform: double the value of whatever variable (GDP deflator, price index, exchange rate, etc.) serving as the *numeraire* price. The result should be a doubling of all prices and nominal magnitudes (like government revenues), but no change in real quantities. If this is not the case, the model is not homogeneous of degree zero.

The most common problem is that some price or nominal magnitude is being fixed independently of the *numeraire*. For example, in the Cameroon model, if government consumption (gdtot) were specified as a nominal rather than a real magnitude, and if it were fixed outside the model, then doubling the GDP deflator would lead to substantial real effects, because a constant *nominal* level of government consumption implies a sizeable *real* decline, which would bring about real adjustments.

6. Running the model: The Dutch disease example

In this section, we use the multisectoral CGE model developed with GAMS in the previous section and, using data for Cameroon, apply it to analysis of the effect of an oil boom on the economy, including consideration of how the results relate to the usual conclusions of the Dutch disease literature.

Because we will be focusing on the response of exports, imports, and production to the inflow of resources, it is useful first to summarize the salient features of the Cameroon economy. Table 13 shows the structure of trade and output in the Cameroon economy in 1979–80, the base year for the model. Six sectors are distinguished, all of which are tradable to some extent. The importance of trade varies substantially, ranging from nearly closed in food and forest crops (exports are 8% of output, imports are only 1 percent of domestic supply), to high net exporters in cash crops (exports are 95% of output), and high net

Table 13
Trade and output in the Cameroon economy

	(Billion 1979–80 CFAF and percent)					
	Output (X)	Exports (E)	Exports/ output (E/X)	Imports (M)	Imports/ domestic supply (M/D)	Armington elasticity (rhoc)
Food & Forest Crops	359.98	26.93	7.5%	2.48	0.7%	1.30
Cash Crops	131.45	125.07	95.1%	8.04	126.0%	0.90
Food Proc & Consumer Gds	190.45	29.32	15.4%	55.02	34.1%	1.25
Intermed & Construct Gds	318.55	111.83	35.1%	188.19	91.0%	0.60
Capital Gds & Construction	184.42	3.84	2.1%	134.72	74.6%	0.40
Public & Private Services	779.77	81.63	10.5%	74.44	10.7%	0.40
Total	1964.62	378.61	19.3%	462.89	29.2%	

importers in intermediate and construction goods (imports are 91% of domestic supply). Note that the CES substitution elasticities are higher for food processing and consumer goods, and food and forest crops, than for intermediate, construction, and capital goods.

The oil sector in Cameroon (and frequently in other countries as well) can be treated as an enclave: the physical location is distant from the rest of the economy, its use of domestic labor is limited, the capital resources required are sector-specific, and the main impact on the larger economy is through the inflow of oil sector earnings. Therefore, we take a shortcut in our modelling approach, and ignore the productive side of the oil sector. Instead, to simulate the impact of higher oil revenues, we simply inject a specific amount of foreign earnings into the economy. In the model, because FSAV is channeled directly into investment, this is equivalent to the assumption that the treasury receives the oil earnings and uses them *entirely* for investment. The amount we experiment with is \$500 million, which roughly approximates Cameroon's oil earnings for 1982.[25]

Table 14 summarizes the macroeconomic effect of the experiment. Domestic prices rise by 26%, nominal wages by 27%, and, driven by the assumption that the incremental earnings are fully invested, real fixed investment grows by 37%. With the nominal exchange rate fixed as a consequence of Cameroon's membership in the CFA zone, the sizeable domestic inflation implies a significant *real* appreciation, as one would expect from a substantial capital inflow.

Table 15 presents the sectoral results from the experiment. The effect of oil revenues on foreign trade is as expected from the real exchange rate movement. Imports increase in all sectors, increasing by 23% overall. Exports drop in all sectors except for the capital goods and construction sector (which represents less than 1% of total exports), with aggregate exports down by 11%. The rise in sectoral prices is linked as well to the sector's tradability: prices rise relatively less in sectors that are more "tradable" in that they are closely linked to external markets (high exports and/or imports). Because domestic prices provide the impetus for the movement of labor across sectors, the larger price increases in the less traded sectors draw labor away from the more traded sectors.[26]

With investment booming, production grows most in capital goods and construction

Table 14
Macroeconomic change

(Percentage change from base)	
GDP deflator (PINDEX)	23.8%
Domestic prices (_PD)	26.0%
Composite prices (_PQ)	19.9%
Nominal wages (WF)	27.0%
Real wages (WF/PINDEX)	2.6%
Foreign savings (FSAV)	1360.4%
Household savings (HHSAV)	28.1%
Government savings (GOVSAV)	19.7%
Depreciation (DEPREC)	19.1%
Total savings (SAVING)	59.2%
Fixed investment (FXDINV)	63.2%
Real investment (_DK)	37.0%
Tariff revenue (TARIFF)	27.3%
Indirect taxes (INDTAX)	18.7%
Total revenue (GR)	22.4%

(24%), resulting in a 52% increase in the sector's labor force. The sector worst hit is cash crops, which experiences a 13% decline in output and loses 21% of its labor force. The food and forest crops sector expands somewhat, largely because trade is so small in the sector that it behaves more like a nontradable sector.

7. Conclusion

This article described the steps necessary to build a multisectoral computable general equilibrium (CGE) model for a developing country. First, we linked the model to the social accounting matrix (SAM) for the economy, and then presented the model equations and their derivation in detail. We then illustrated how the model could be implemented, using GAMS, which provides a concise way to combine model data and equations. Calibrating the model

Table 15
Sectoral results

	(Percentage change from base)				
	Output (X)	Exports (E)	Imports (M)	Domestic prices (PD)	Labor force (FDSC)
Food & Forest Crops	2.3%	−9.9%	35.5%	23.3%	3.7%
Cash Crops	−13.3%	−13.5%	7.0%	21.0%	−20.9%
Food Proc & Consumer Gds	−1.7%	−17.3%	30.7%	23.0%	−2.5%
Intermed & Construct Gds	−3.3%	−11.1%	15.7%	26.4%	−5.7%
Capital Goods & Construction	23.5%	9.1%	39.1%	34.0%	51.9%
Public & Private Services	−0.5%	−7.8%	9.9%	25.8%	−0.3%
Total	0.8%	−11.4%	23.3%	26.0%	0.0%

to the base data set provided by the SAM was described. We concluded with an application of the model developed in earlier sections to the analysis of Dutch disease in the Cameroon, which gave results broadly consistent with the received wisdom on the effect of a booming sector, but also revealed the richer results that could be obtained from an empirical approach. The varying degree of tradability was found to be an important determinant of sectoral response to the resource boom, with important implications for policy.

Notes

1. The GAMS CGE model is based on a model of the United States described in detail in Robinson, Kilkenny, and Hanson (1990).
2. In many models, including the U.S. model described in Robinson, Kilkenny, and Hanson (1990), there is a separate "enterprise" account that receives capital income, pays corporate taxes, saves (retained earnings), and distributes dividends and profits.
3. In the 1-2-3 model presented in Article 2, the corollaries to Equations 3 and 4 are described as cost functions arising from first-order conditions for the CES and CET functions. However, because CES and CET aggregation functions are linearly homogeneous, we can replace the cost functions with the accounting identities shown (showing each price as the average of a traded price and a domestic price), since the first-order conditions will be incorporated in the import demand and export supply functions presented later.
4. This approach was adopted by Johansen (1960) in the first CGE model. Of course, numerous other nested relationships are possible and many have been used in CGE models, including some that eliminate the fixed coefficients combination of value added and intermediate inputs.
5. Note that for sectors with no imports and/or no exports, the CES and CET functions in Equations 11 and/or 14 are not needed.
6. It is possible to weaken these strong assumptions without losing the fundamental property that domestic and foreign goods are imperfect substitutes.
7. The two households shown here are only indicative of the mapping schemes that can be used to move from factor incomes to households in CGE models. In applications, the mapping choice is driven by the focus of the model (i.e., models concerned with income distribution will have more elaborate mappings) or by the availability of data on household expenditure patterns (adding additional households all sharing the same consumption and savings pattern will add nothing to the model's richness).
8. Note that, given the definition of P^k: $FXDINV = \Sigma_i P_i^k \cdot DK_i = \Sigma_i P_i^q \cdot ID_i$.
9. The same reasoning can be used to justify why there is no separate market-clearing condition for domestic output (X), because this involves adding exports to both sides of this adjusted market-clearing condition.
10. In fact, the wfdist parameters become endogenous for all but one sector. This asymmetry occurs because fixing capital stocks in n sectors requires n new variables to ensure that Equation 9 is satisfied. Because the market clearing condition is automatically satisfied, the average return to capital (WF_1) is no longer needed to

clear the market, so that WF_1 together with $n - 1$ wfdist variables are sufficient to satisfy Equation 9. In practice, it is convenient to fix WF_1 to one, and solve for the n wfdist parameter.

11. The role of the real exchange rate in this class of models has been much discussed, often in a very confused way. See, for example, Whalley and Yeung (1984), who introduce a "parameter" that equilibrates the balance of trade equation, but which they avoid calling the real exchange rate. These issues have been recently sorted out by de Melo and Robinson (1989) and in Article 2 of this volume, where it is shown that these models can be seen as extensions of the "Salter-Swan" model of a small, open economy with nontradables.
12. Recent discussions of macro closure in developing country CGE models are in Article 8 of this volume, as well as Robinson (1989), Adelman and Robinson (1988), Dewatripont and Michel (1987), and Rattso (1982). The seminal article on macro closure is Sen (1963). See also Taylor (1990).
13. For a more complete analysis of Dutch Disease in the Cameroon using this CGE model, see Benjamin, Devarajan, and Weiner (1989).
14. In the following discussion, no previous exposure to GAMS is assumed. For a thorough introduction to model-building in GAMS, see Brooke, Kendrick, and Meeraus (1988).
15. If the set of sectors with non-zero imports is the same as the set with non-zero exports, then the two separate indices IE and IM can be replaced with a single index, IT. The separate index approach used here is preferable, however, since it will also work for the case when IE = IM, and therefore allows for the model equations to be written without reference to the specific data for a particular country or application.
16. Note that GAMS does not require that the variable being "determined" in each equation appear alone on one side of the equation. So whereas P^v was alone on the left side of equation (5) in Table 1, the corresponding equation in Table 8 has PV combined with other elements on the right side of the equality.
17. As discussed earlier, it is easy to modify the assumption of mobility for capital or any other primary factor. The major implication is that with the sectoral demands (FDSC) for some factor fixed, something else must be permitted to adjust so that the PROFITMAX equation holds. The easiest approach is to allow the wfdist parameters to adjust, which in economic terms corresponds to allowing factor returns to differ in all sectors, with no exogenous pattern imposed. To achieve this result in GAMS, the wfdist array must be declared as a VARIABLE, rather than as a PARAMETER, which (by definition) remains fixed. WFDIST then can vary freely so that the first order condition holds.
18. Note that in GAMS, whether a particular variable is fixed or flexible is determined by whether it is declared as a PARAMETER (fixed) or VARIABLE (flexible) in the GAMS program, not by whether or not it is upper or lower case. GAMS does not distinguish between upper, lower, or mixed case.
19. Because of this closure choice, in which EXR is fixed exogenously, PINDEX is not in fact the numeraire in the model, despite the earlier discussion of this as the

"numeraire" equation. EXR serves as the numeraire, and changes in PINDEX serve to vary the real exchange rate and equilibrate the balance of trade.

20. This approach was used for the U.S. tax model developed by Ballard, Fullerton, Shoven, and Whalley (1985).
21. Again, the importance of these investment allocation shares depends on the use of the model. If the model is applied exclusively to comparative statics experiments, then the investment allocation shares do not matter at all (as long as the sectoral composition of capital is the same in all sectors), since the investment is not added to the existing capital stock and therefore does not affect production. Only in multi-period simulations will the investment allocation shares have any influence.
22. Although feasible, note that this choice of unitary initial prices is not usually applied to wage rates, because doing so would change the units in which labor inputs were measured from "persons" to some fraction or multiple of a person, which would differ from one labor category to another.
23. In GAMS, it is important that parameters that should sum to one be computed so that they sum to one with the full accuracy of the computer being used.
24. GAMS can assist in this process, because it is possible to calculate and list how far all of the equations are from equilibrium *before* GAMS has started to find a solution.
25. Both the model and the simulations reported here are similar to those presented in Benjamin, Devarajan, and Weiner (1989). The interested reader is referred there for a more complete discussion of the Cameroon experience, as well as a more complete discussion of alternative simulation results. The experiment is implemented very easily and is shown in the GAMS listing in Appendix 1.
26. Note that sectoral capital stocks are assumed fixed, and labor is assumed fully employed. Thus, the total change in employment is zero, and the change in total output is limited to the effect of intersectoral labor reallocation, because aggregate capital and labor are unchanged.

Appendix 1: Equations, variables, and parameters in the CGE model

Equations

(1) $$P_i^m = pw_i^m(1 + t_i^m)\,R$$

(2) $$P_i^e = PW_i^e(1 + t_i^e)\,R$$

(3) $$P_i^q = \frac{P_i^d \cdot D + P_i^m \cdot M}{Q}$$

(4) $$P_i^x = \frac{P_i^d \cdot D + P_i^e \cdot E}{X}$$

(5) $$P_i^v = P_i^x(1 - t_i^x) - \sum_j P_j^q \cdot a_{ji}$$

(6) $P_i^k = \sum_j P_j^q \cdot b_{ji}$

(7) $PINDEX = \dfrac{GDPVA}{RGDP}$

(8) $X_i = a_i^D \prod_f FDSC_{if}^{\alpha_{if}} \quad (FDSC_{i1} = capital\ stock)$

(9) $WF_f \cdot wfdist_{if} = P_i^v \cdot \alpha_{if} \dfrac{X_i}{FDSC_{if}}$

(10) $INT_i = \sum_j a_{ij} \cdot X_j$

(11) $X_i = a_i^T [\gamma_i E_i^{\rho_i^T} + (1 - \gamma_i) D_i^{\rho_i^T}]^{1/\rho_i^T 1}$

(12) $E_i = D_i \left[\dfrac{P_i^e (1 \gamma_i)}{P_i^d < \gamma_i} \right]^{1/\rho_i^T}$

(13) $E_i = econ_i \left[\dfrac{PW_i^e}{pwse_i} \right]^{\eta_i}$

(14) $Q_i = a_i^C [\delta_i M_i^{\rho_i^C} + (1 - \delta_i) D_i^{-\rho_i^C}]^{1/\rho_i^C}$

(15) $M_i = D_i \left[\dfrac{P_i^d \cdot \delta_i}{P_i^m (1 - \delta_i)} \right]^{1/1+\rho_i^C}$

(16) $Y_f^F = \sum_i WF_f \cdot FDSC_{if} \cdot wfdist_{if}$

(17) $Y_{cap \epsilon h}^H = Y_1^F - DEPREC \qquad (Y_1^F = capital\ factor\ income)$

(18) $Y_{lab \epsilon h}^H = \sum_{f \neq 1} Y_f^F$

(19) $TARIFF = \sum_i pw_i^m \cdot M_i \cdot t_i^m \cdot R$

(20) $INDTAX = \sum_i P_i^x \cdot X_i \cdot t_i^x$

(21) $HHTAX = \sum_h Y_h^H \cdot t_h^h \quad h = cap,\ lab$

(22) $EXPSUB = \sum_i PW_i^e \cdot E_i \cdot t_i^e \cdot R$

(23) $GR = TARIFF + INDTAX + HHTAX - EXPSUB$

(24) $DEPREC = \sum_i depr^i \cdot P_i^k \cdot FDSC_{i1}$ $\quad (FDSC_{i1} = capital\ stock)$

(25) $HHSAV = \sum_h Y_h^H \cdot (1 - t_h^H) \cdot mps_h$

(26) $GOVSAV = GR - \sum_i P_i^q \cdot GD_i$

(27) $SAVING = HHSAV + GOVSAV + DEPREC + FSAV \cdot R$

(28) $CD_i = \frac{\Sigma_h[\beta_{ih}^H \cdot Y_h^H \cdot (1 - mps_h) \cdot (1 - t_h^H)]}{P_i^q}$

(29) $GD_i = \beta_i^G \cdot gdtot$

(30) $DST_i = dstr_i \cdot X_i$

(31) $FXDINV = INVEST - \sum_i P_i^q \cdot DST_i$

(32) $P_i^k \cdot DK_i = kshr_i \cdot FXDINV$

(33) $ID_i = \sum_j b_{ij} \cdot DK_j$

(34) $GDPVA = \sum_i P_i^v \cdot X_i + INDTAX + TARIFF$

(35) $RGDP = \sum_i (CD_i + GD_i + ID_i + DST_i + E_i - pw_i^m \cdot M_i \cdot R)$

(36) $Q_i = INT_i + CD_i + GD_i + ID_i + DST_i$

(37) $\sum_i FDSC_{if} = fs_f$

(38) $pw_i^m \cdot M_i = PW_i^e \cdot E_i + FSAV$

(39) $SAVING = INVEST$

Variables

C_i	Final demand for private consumption	M_i	Imports
D_i	Domestic sales of domestic output	P_i^d	Domestic sales price
DEPREC	Total depreciation charges	P_i^e	Domestic price of exports
DK_i	Investment by sector of destination	P_i^k	Price of a unit of capital in each sector
DST_i	Inventory investment by sector	P_i^m	Domestic price of imports
E_i	Exports	P_i^q	Price of composite good
EXPSUB	Total export subsidies	P_i^v	Value added price
$FDSC_{if}$	Factor demand	PW_i^e	World price of exports
FSAV	Foreign savings	P_i^x	Output price
FXDINV	Fixed capital investment	PINDEX	GDP deflator
G_i	Government final demand	Q_i	Composite goods supply
GDPVA	Nominal GDP in market prices	R	Exchange rate
GOVSAV	Government savings	RGDP	Real GDP
GR	Total government revenue	SAVING	Total savings
HHSAV	Total household savings	TARIFF	Tariff revenue
HHTAX	Household tax revenue	WF_f	Average factor price
ID_i	Final demand for investment goods	X_i	Domestic output
INDTAX	Total indirect tax revenue	Y_f^F	Factor income
INT_i	Intermediate input demand	Y_h^H	Household income
INVEST	Total investment		

Parameters

a_{ij}	Input-output coefficients	$pwse_i$	World price of export substitutes
a_i^C	CES function shift parameter	t_h^H	Household income tax rate
a_i^D	Production function shift parameter	t_i^e	Export subsidy rates
a_i^T	CET function shift parameter	t_i^m	Tariff rate on imports
$alpha_{if}$	Production function share parameter	t_i^x	Indirect tax rate
b_{ij}	Capital composition matrix	$wfdist_{if}$	Factor market distortion parameters
$depr_i$	Depreciation rate	α_{ij}	Production function exponents
$dstr_i$	Inventory investment ratio	β_i^G	Government expenditure shares
$econ_i$	Export demand shift parameter	β_{ih}^H	Household expenditure shares
fs_f	Aggregate factor supply	δ_i	CES function share parameter
gdtot	Real government consumption	η_i	Export demand price elasticity
$kshr_i$	Investment destination shares	γ_i	CET function share parameter
mps_h	Household saving rates	ρ_i^C	CES function exponent
pw_i^m	World price of imports	ρ_i^T	CET function exponent

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