Chapter 2

A Recursive Dynamic Computable General Equilibrium Model

Xinshen Diao and James Thurlow

The relationship between economic growth and poverty is complex, especially in developing countries where inadequate time series data often makes ex post analysis difficult. This has led to uncertainty over the role of growth in reducing poverty (see, for example, Ravallion 2003; Deaton 2005; Sala-i-Martin and Pinkovskiy 2010). At its core, the growth–poverty relationship is determined by a country's economic structure, that is, the linkages among sectors, regions, and institutions. It involves macroeconomic considerations, such as fiscal budgets and current accounts, and microlevel decisionmaking of producers and households. It is mediated through (and constrained by) product and factor markets.

Several methods are available to evaluate ex ante the impact of policies and external shocks in developing countries.[1] These tend to focus on specific aspects of the growth–poverty relationship. Farm models, for example, capture detailed behavior of representative producers as they maximize their welfare by allocating resources between competing activities. However, these models usually treat prices as given and so evaluate microlevel decisions in isolation from broader markets and macroeconomic effects. In contrast, multimarket models explicitly capture market interactions and estimate price and income changes in response to external shocks. However, they sacrifice some of the detail of farm models by excluding the decisionmaking of individual agents. They also tend to focus on particular sectors, such as agriculture, and rarely take economywide linkages or resource constraints into account. An important omission here is factor markets, which often influence a country's growth path and income distribution. Finally, multiplier models capture economywide linkages, but they also tend to assume fixed prices and unconstrained factor resources. Each partial equilibrium approach is limited in its coverage of the growth–poverty relationship and the policy options facing developing countries.

In this chapter we describe a computable general equilibrium (CGE) model that incorporates many aspects of the growth–poverty relationship. Its general equilibrium specification reflects a country's economic structure and linkages and captures the interactions between different decisionmaking agents in a market-based economy. Although theoretically grounded, CGE models are calibrated to observed data and so provide a semiempirical simulation laboratory for evaluating different policy options. We first describe our economywide framework, before presenting the CGE model's mathematical specification. The model's data sources and calibration procedure are then described, followed by the poverty and nutrition modules. The general features and workings of the model are summarized in nonmathematical language, and the final section identifies some of the model's main limitations.

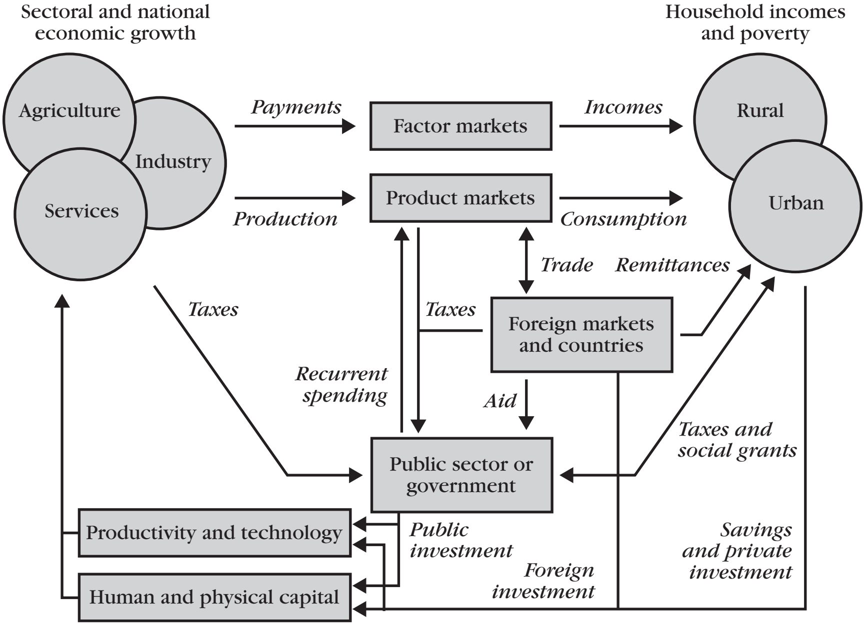
Economywide Framework

CGE models are designed to capture the linkages between sectoral and national economic growth on the one hand and household incomes and poverty on the other (Figure 2.1). Direct and indirect transmission channels link growth to poverty, and these are largely determined by a country's economic structure. Production-side linkages are influenced by sectors' technologies. Backward production linkages arise when producers demand intermediate inputs. When agricultural production expands, it uses intermediate goods, such as fertilizers and transport, thereby stimulating nonagricultural production. The more input intensive a sector is, the stronger its backward linkages are. Conversely, forward production linkages account for the supply of inputs to downstream industries. When agricultural production expands, it can supply more goods to food processors, which again raises nonagricultural production.

Consumption linkages occur when household incomes are used to buy goods and services. When agricultural production expands, it raises farmers' incomes, which are then used to purchase farm and nonfarm goods. The size of consumption linkages depends on the share of factor income distributed to households, the composition of the consumption basket, and the share of domestically supplied goods in consumer demand. Evidence from developing countries suggests that consumption linkage effects are much larger than production linkage effects (that is, they account for 75–90 percent of total growth multiplier effects in Sub-Saharan Africa and 50–60 percent in Asia; see Haggblade, Hammer, and Hazell 1991). Agricultural growth multipliers are especially important in Sub-Saharan Africa (Delgado, Hopkins, and Kelly 1998).

Our model captures production and consumption linkages when evaluating economic growth. The model contains production functions disaggregated by sector

Figure 2.1—Economywide conceptual framework



Source: Authors.

and subnational regions. Representative producers each have a unique production technology determining their linkages to other sectors. The production functions combine the factors of production (for example, land, labor, and capital), and this generates incomes for factors and households. As with producers, the model differentiates among household groups, and the distribution of factor incomes depends on households' unique factor endowments. Households consume commodities based on their set of preferences and utility functions. This general equilibrium structure allows us to trace the contribution of sectoral production to national economic growth and to household incomes and expenditures via product and factor markets.

The model also covers the public sector. The government levies direct and indirect taxes. It uses these revenues to pay for recurrent consumption spending, which in turn generates demand for producers' goods and services. The government also pays for social grants and makes capital investments. The government may receive financial assistance from abroad through borrowing or foreign aid. Foreign markets are also a source of export demand and a supplier of imports. The size of growth multiplier effects is determined by the combined export-intensity and import-penetration ratios of individual sectors. A country with high export intensity faces less stringent domestic demand constraints, whereas a higher import penetration ratio means greater competition from foreign producers. The CGE model captures these interactions with the rest the world by using trade functions and tracking international transfers. Finally, our CGE model is recursively dynamic. Savings are collected into a national pool and are used to finance investment. Investment is converted into capital stocks to determine the rate of capital accumulation. Changes in factor supplies and productivity determine the overall rate of economic growth in the country. In some cases the rate of technical change is linked to the level and composition of investments.

Mathematical Specification of the Model

Following the tradition of general equilibrium theory, perfect competition is a key assumption in our CGE model, at least for domestic product markets. By assuming a market-based economy, our model solves for the equilibrium between demand and supply of individual factors and products, as mediated by changes in relative prices. Given the model's multisector, multifactor, and sometimes multiregional setting, the economic structure of an economy (to which to the model is calibrated) will affect the ability of producers and consumers to respond to changing prices. Economic structure therefore influences changes in the distribution of incomes across household groups. The process of calibrating the model to the structure of an economy is described later in this chapter. Here we present the model specification using a series of mathematical equations that explain the behavioral responses of economic agents (for example, consumers, producers, and the government). Because this is a general equilibrium model, we also present equations that maintain economywide or macroeconomic consistency. We then discuss the dynamic processes of the model. The concluding section of this chapter discusses some of the model's main limitations.

Consumer Behavior

For a recursively dynamic model, consumer behavior is assumed to be the same as in a static model. Thus, typical consumers (and there can be more than one in the model) maximize their welfare (represented by a utility function) facing a budget constraint. Using a Stone-Geary utility function, the consumer problem can be presented mathematically as:

$$\text{Max} \prod_j (C_{hj} - \gamma_{hj})^{\beta_{hj}}$$

$$\text{subject to } \sum_j (P_j \cdot C_{hj}) = (1 - s_h - ty_h) Y_h,$$

where $j \in J$ and $h \in H$, and J and H are sets for commodities and households, respectively. C is the level of consumption for good j consumed by household h, γ is a minimum subsistence level of consumption for good j, and β stands for marginal budget share (that is, the share of the next "dollar" of income spent on good j). Consumption-based utility is maximized subject to the budget constraint equation, in which P is the market price faced by the consumers, s is the saving rate (defined later), ty is an income tax rate, and Y is total income.

Savings of household h is equal to $s_h Y_h$. In a recursive dynamic model, consumers' saving decisions cannot be solved simultaneously with their consumption decisions, because they face an intratemporal maximization issue rather than an intertemporal one. Savings rates in recursive models are usually an exogenous variable, which is similar to Solow-style growth models, in which the total amount of savings adjusts over time in proportion to income levels. This choice greatly simplifies the dynamics in recursive models, because savings cannot be used to smooth consumption over time, as is the case in Ramsey-style intertemporal dynamic models.[2] This is an obvious caveat of our model. However, the dynamic optimization issue is less important for our purposes, because we are less concerned with how to allocate income over time to maximize a time-discounted utility function and reach steady-state equilibrium. Rather, the model developed in this chapter is used to evaluate structural linkages and economic growth paths over a relatively short period of about 10–15 years. A longer period is normally required for intertemporal optimization problems. Moreover, factor accumulation and technical change, rather than savings, are the sources of economic growth in our model. This assumption is reasonable, given that private savings are usually very low in low-income African countries.

Maximizing the consumer utility function generates the following set of demand functions, which are the equations applied in the CGE model for the consumer problem:

$$C_{hj} = \gamma_{hj} + \beta_{hj}[(1 - s_h - ty_h)Y_h - \Sigma_i(P_i \cdot \gamma_{hi})]P_j^{-1}, \tag{1}$$

where $i \in J$. Equation 1 is known as a linear expenditure system (LES) of demand. It permits changes in consumption patterns over time, because the subsistence level of consumption γ can vary across products and so cause the pattern of additional spending to differ from past spending. In the other words, unlike the Cobb–Douglas demand system, the LES allows for nonunitary income elasticities of demand. Therefore, although all goods are assumed to be normal (that is, have a positive income elasticity), the LES can distinguish between necessity goods (elasticity less than one) and luxury goods (elasticity greater than one). When marginal rather than average budget shares enter the demand system and there is nonzero subsistence consumption of basic commodities, then the various consumers in the model will respond differently to similar changes in incomes and market prices. For example, when household incomes rise, poor households may increase the share of their income spent on foods (that is, with an income elasticity greater than one), whereas rich households may reduce their food expenditure share (that is, with an elasticity less than one). This variation in responses explains why CGE models usually consider multiple types of consumers (or household groups), often distinguished by geographic location, rural or urban areas, income sources, or poor/nonpoor status. As discussed below, income elasticities are usually estimated econometrically using nationally representative household expenditure surveys.

Producer Behavior

Producers are defined at the sector level. A typical producer maximizes profits, given a set of input and output prices. Consistent with neoclassical general equilibrium theory, we assume constant returns to scale technology. Accordingly, a constant elasticity of substitution (CES) function is chosen as the production function for each sector:

$$X_i = \Lambda_i \left(\sum_f a_{if} \cdot V_{if}^{-\rho_i} \right)^{-1/\rho_i}, f \in F, \tag{2}$$

where X is the output quantity of sector i, Λ is a shift parameter reflecting total factor productivity (TFP), V is the quantity demanded of each factor f (land, labor, and capital), F is the set of factors, and α is a share parameter of factor f employed in the production of good i.[3] As with any production function, producers combine the factors of production to produce a certain level of output. Here ρ is a parameter to capture the substitution relationship between factors, that is, ρ transfers the elasticity of substitution, σ, in the following way: ρ $(\sigma = 1/(1 + \rho))$. Thus, unlike a Cobb–Douglas function, in which the substitution elasticity is always unitary, the CES production function allows for a wider range of substitution possibilities between different factors in response to relative price changes. A higher elasticity means that it is easier for producers to switch between factors (that is, the system is more responsive to relative factor price changes), whereas a low elasticity represents a more rigid factor market system.

Profits π in sector i are defined as the difference between revenues and total factor payments:

$$\pi_i = PV_i \cdot X_i - \sum_f (W_f \cdot V_{if}),$$

where PV_i is the value-added component of the producer price, and W_f is factor price (for example, labor wages and land or capital rents). Maximizing sectoral profits subject to Equation 2 and rearranging the resulting first-order condition provides the system of factor demand equations used in the model:

$$V_{if} = \Lambda_i^{-\frac{\rho_i}{1+\rho_i}} \cdot X_i \left(\alpha_{if} \cdot \frac{PV_i}{W_f} \right)^{1/(1+\rho_i)}. \tag{3}$$

Equation 3 shows how demand for an individual factor V falls when its cost W rises relative to the composite price of all other factors PV. It should be noted that it is relative rather than absolute price changes that matter in the CGE model. If PV and W increase or decrease at similar rates, then factor demand is unaffected (factor demands will increase proportionally with changes in output X).

Intermediate inputs are also used in the production process. Leontief technology is assumed for the relationship between intermediate input use and gross output. Demand for intermediates is determined by the fixed input–output coefficients $io_i'i$ between good i' used in the production of output i. The complete producer price PP is then defined as:

$$PP_i = PV_i + \sum_j P_j io_{ji}. \tag{4}$$

Equation 4 shows how the producer price is not only affected by PV, which is a combination of factor prices taking into consideration sector-specific technology. It is also affected by the prices of intermediate inputs weighted by the intensity of their use. The equation indicates possible interindustry linkages through competition for similar factors among sectors and through competition over the supply of intermediate inputs. These production linkages are best captured by a general equilibrium model that accounts for the use of both factors and intermediates in the production process. This consideration is important for our analysis, because production linkages are usually weaker for traditional agriculture, which typically uses few modern intermediate inputs (for example, fertilizer). Resource constraints and price responses are also important considerations when evaluating the relationship between economic growth and poverty reduction.

Behavioral Functions Governing International Trade

In most partial equilibrium and theoretical general equilibrium models, international trade occurs when domestic demand does not equal domestic supply. Imports are defined as excess demand for a particular good, whereas exports are excess supply. In this framework, it is impossible to have both imports and exports for the same good, because domestic and foreign goods are implicitly assumed to be perfect substitutes. Such an assumption may be acceptable when analyzing a highly disaggregated commodity. However, more aggregated commodity groupings and different varieties can result in simultaneous imports and exports for what would appear to be a single commodity (for example, white and yellow maize). In fact, trade data reveal two-way trade for most commodities and most countries. For manufactures, one can readily assume that a traded commodity is in fact a group of different varieties of the same good (for example, textiles or vehicles). Consumers have preferences not only for the commodity but also for varieties of a given commodity. Observing this phenomenon, Armington (1969) developed a structural model in which a domestically produced and consumed good is an imperfect substitute for similar imported goods. This approach has become the standard approach in CGE modeling to capture two-way trade (when such trade is observed in trade data). We therefore also assume imperfect substitution between domestic goods and goods supplied to and from foreign markets. CES functions are used to define the relationship between domestically produced and imported goods:

$$Q_i = \Omega_i \left[\mu_i \cdot D_i^{-\theta_i} + (1 + \mu_i) M_i^{-\theta_i}\right]^{-1/\theta_i} \tag{5}$$

$$(1 - tc_i) P_i \cdot Q_i = PD_i \cdot D_i + PM_i \cdot M_i \tag{6}$$

$$PM_i = (1 + tm_i) pwm_i,$$

where Ω is the shift parameter in the function and μ_i is the share parameter for domestically produced good D_i in the composite good Q_i, while M_i are imported quantities of the same good to supply the domestic market, θ_i is the parameter to capture the substitution relationship between imported quantities and domestically produced quantities to form Q_i, PD_i is the price of D_i, tc is an indirect sales tax, tm is the import tariff rate, and pwn is the world import price. Substitution occurs when the relative price of a domestic and imported good changes. For example, if the import price remains unchanged, then domestic goods will substitute for imports if the domestic price falls. Domestic prices may fall if, for example, productivity increases. Similarly, lowering tariffs through trade liberalization should cause import prices to fall relative to domestic prices. The import price PM in our model is determined exogenously by world import prices pwm and import tariff rates tm under the small country assumption. When import prices fall, imports substitute for domestic goods, causing domestic production to fall. Both situations are plausible. Thus, an advantage of CGE models is that they capture both direct and indirect substitution effects.

Imperfect substitution is also assumed for exports. A constant elasticity of transformation (CET) function determines the relationship between the quantity of goods produced for domestic and foreign export markets:

$$X_i = \Gamma_i \left[\tau_i \cdot D_i^{\varphi_i} + (1 + \tau_i) E_i^{\varphi_i}\right]^{1/\varphi_i} \quad (7)$$

$$PP_i X_i = PD_i \cdot D_i + PE_i \cdot E_i \quad (8)$$

$$PE_i = (1 - te_i) pwe_i,$$

where Γ is the shift parameter in the function and τ_i is the share parameter for domestically produced good D_i in total output of good X_i, while E_i is exported quantities of X_i, ϕ_i is the parameter to capture the substitution relationship between exported quantities and domestically produced quantities of X_i, te is the export tax rate, and pwe is the exogenous world export price. Analogous to import substitution, the CET export function allows producers to switch between supplying domestic and foreign markets, depending on relative price changes. If domestic prices rise relative to export prices, then producers increase supply to domestic markets and reduce exports in order to maximize revenues. Similarly, when world prices (and hence export prices) increase, such as during the recent food-price crisis, then producers will increase exports and reduce domestic supply. This decision may be offset by rising domestic prices caused by reduced domestic supply.

The level of imports and exports for an individual commodity is solved using Equations 5–8. Maximizing $P_i Q_i - PD_i D_i - PM_i M_i$ subject to Equation 5 and rearranging the resulting first-order condition gives the following equation defining the ratio of D and M:

$$\frac{D_i}{M_i} = \left(\frac{\mu_i}{1 - \mu_i} \cdot \frac{PM_i}{PD_i}\right)^{1/(1 + \theta_i)}. \quad (9)$$

Similarly, minimizing $PP_i X_i - PD_i D_i - PE_i E_i$ subject to Equation 7 gives the ratio of D and E:

$$\frac{D_i}{E_i} = \left(\frac{\tau_i}{1 - \tau_i} \cdot \frac{PD_i}{PE_i}\right)^{1/(\varphi_i - 1)}. \quad (10)$$

The above two equations specify the substitution responses described earlier (between relative prices and quantities). The ease with which producers or consumers switch between domestically produced and foreign goods is determined by elasticities of substitution θ and ϕ. Larger elasticities permit greater responsiveness to relative price changes. These elasticities can be estimated based on historical quantity–price relationships using econometrics or back-casting techniques (see, for example, Arndt, Robinson, and Tarp 2002).

Equilibrium Conditions

A key difference between partial and general equilibrium models is the determination of prices. In most partial equilibrium models, prices are either exogenously given or determined by predefined price functions. In general equilibrium theory, all factor and commodity prices are determined endogenously by market equilibrium conditions. Without international factor mobility, factor prices W are fully endogenous. To simplify our discussion, we initially assume that all factors are fully employed and mobile across sectors. This implies the following factor market equilibrium condition:

$$\sum_i V_{if} = \overline{VS}_f, \tag{11}$$

where $\overline{VS}_f$ is the total factor supply and V_{if} is factor demand in each sector (determined in Equation 3). Total factor supply is fixed in any given year. Any changes to $\overline{VS}_f$ must be determined exogenously or independently of the forces influencing V_{if}. Equation 11 determines factor returns W_f, which are therefore affected by sector-level factor demands and the total supply of each factor.

The second key feature distinguishing general equilibrium models is their treatment of household incomes, which, via the budget constraint, determines consumer demand for individual commodities. Partial equilibrium models often treat income as an exogenous variable or something determined by forces other than the production system. In general equilibrium models, income is generated from the returns earned by factors (and by remittance transfers, when they exist). To simplify our discussion, we assume all factors are owned by households,[4] such that household income Y is determined by

$$Y_h = \sum_{if} \delta_{hf}(1 - tf_f)\, W_f \cdot V_{if}, \tag{12}$$

where δ is a coefficient matrix that sums to one and determines the distribution of factor earnings among individual households. Direct taxes tf_f are imposed on total factor $\overline{VS}_f$'s earnings (for example, corporate taxes on capital profits). The distribution of factor incomes is determined by households' factor endowments. For example, higher income households are usually better endowed with capital and skilled labor, and so these households receive the most capital profits and a larger share of skilled labor's wage income than do lower income households. The value of δ is therefore the driving factor behind distributional outcomes in our model. As discussed in the next subsection, information on household income sources is drawn from household survey data.

Domestic prices are determined by equilibrium conditions in the product market. As foreign demand and exports are determined in Equations 9 and 10, market equilibrium can be defined in terms of the composite good Q instead of D as follows:

$$Q_i = \sum_h C_{ih} + N_i + G_i + \Sigma_j (io_{ji} \cdot X_i), \tag{13}$$

where N is investment demand and G is government recurrent consumption spending (both defined later). Changes in right-hand-side variables in Equation 13 reflect shifts in demand, whereas changes in Q represent changes in supply. When changes in total demand and supply are unequal, then domestic prices PD, and hence P, change to establish a new market equilibrium.

The relationship between savings and investment demand N, and taxes and government spending G, will be specified below. However, in the absence of taxes or savings (that is, when ty, tf, s, N, and G are all zero), the above 13 equations simultaneously solve for the values of the 13 endogenous variables (Y, C, X, V, Q, D, M, E, P, PV, PP, PD, and W). The general equilibrium solution defined by the equations only holds if there are no foreign transfers, implying a zero trade balance. This assumption is often made in simple theoretical general equilibrium models, but it is rarely used in CGE models, which need to be calibrated to observed data for a country. Later we introduce foreign transfers and current account imbalances. Before doing this, however, we first define government G and investment demand N.

Government and Investment Demand

The government in our CGE model appears as a separate institution with incomes and expenditures but without any behavioral functions. In other words, its decision to either consume or invest is not solved as an optimization problem. Total domestic revenues R is the sum of all individual taxes:

$$R = \sum_i (tc_i \cdot P_i \cdot Q_i + tm_i \cdot pwm_i \cdot M_i + te_i \cdot pwe_i \cdot E_i) + \sum_h (ty_h \cdot Y_h) + \Sigma_f (tf_f \cdot W_f \cdot \overline{VS}_f). \tag{14}$$

Tax rates are typically exogenous in a CGE model so that they can be used to simulate policy changes. The government may also receive income from abroad, such as via foreign grants or borrowing and from holding assets. These additional income sources are discussed below when we introduce macroeconomic closure.

Tax rates are typically exogenous in a CGE model so that they can be used to simulate policy changes. Although the government does not attempt to maximize revenues by endogenously changing tax rates, its revenues increase at given tax rates when the economy grows. This allows the government to increase savings and investment, create more public goods, and enhance productivity for the private sector. African governments usually receive additional nontax income from abroad, such as via foreign grants/borrowing and from holding assets. These additional income sources are treated as exogenous to the model and are discussed below when we introduce macroeconomic closure.

The government uses its revenues to purchase goods and services (that is, recurrent consumption spending) and to save (that is, finance public capital investment):

$$R = \sum_i (P_i \cdot G_i) + FB, \tag{15}$$

where G is consumption spending from Equation 13 and FB is the recurrent fiscal balance, which can be positive to represent surplus and negative to represent deficit. Because we do not have behavioral functions that optimize revenues and expenditures, our model does not endogenously balance government accounts. Rather, we assume that G is determined exogenously, implying that an increase in government revenues causes the fiscal surplus (or public savings or investment) to expand (or the deficit to contract). The fiscal balance FB is therefore merely a residual balancing item. In reality, the government also makes transfers to (and receives incomes from) households and firms (such as social grants and contributions). Such transfers are captured in the model as either fixed values or in proportion to changing household populations or incomes. Although such transfers are considered in the CGE model, we exclude them here to simplify the equations.

There is also no behavioral function determining the level of investment demand for goods and services (N from Equation 13). The total value of all investment spending must equal the total amount of investible funds I in the economy. We therefore assume that the value of N for each good i is in fixed proportion to the total value of investment:

$$I \cdot \varepsilon_i = P_i \cdot N_i, \tag{16}$$

where ε is the value share for each good i and P is the market price determined by the equilibrium condition in Equation 13. To determine the value of I we must define the macroeconomic closure.

Current Account and Macroeconomic Closure

Macroeconomic balance in a CGE model is determined by a series of closure rules. The most important of these is for the current account balance. Neoclassical general equilibrium theory does not permit current account imbalances. However, CGE models are often calibrated to observed data for a country, where current accounts are invariably imbalanced. Thus, our model will not be able to achieve equilibrium unless we include external financial flows, such as incomes from holding foreign assets or the government's external borrowing or foreign aid receipts. Current account imbalances must be accounted for, because they affect the real economy via the relationship between exports and imports and between savings and investment. To incorporate these considerations into our model, we start from the well-known identity linking a country's current account balance CA to national savings S and investment I:

$$CA = TE - TM - NFI = S - I = \Delta NFA, \tag{17}$$

$$\text{where } TE = \sum_i (pwe_i \cdot E_i) \text{ and } TM = \sum_i (pwm_i \cdot M_i).$$

The left-hand side of the identity states that a country's current account balance is equal to its trade balance ($TE - TM$) less net foreign incomes NFI. A country is therefore running a current account surplus when the sum of its trade balance and NFI is positive, in which case national savings exceed national investment and there is an accumulation of net foreign assets NFA. Total savings in the economy is the sum of all household savings and the government's recurrent fiscal balance:

$$S = \sum_h (s_h \cdot Y_h) + FB. \tag{18}$$

Before discussing the adopted closure rules, we must first expand two previous equations to include the foreign transfers received by households and the government (that is, the components of NPI). We rewrite Equations 12 and 15 as:

$$Y_h = \sum_{if} (\delta_{hf}(1 - tf_f) W_f \cdot V_{if}) + hw_h \tag{12'}$$

$$R + rw = \sum_i (P_i \cdot G_i) + FB, \tag{15'}$$

where hw are foreign transfers received by households (for example, remittances) and rw are incomes earned by the government (for example, foreign aid). If transfers are negative, then they denote net foreign payments (such as interest paid on foreign debt). Given these new Equations 12′ and 15′, the value of *NFI* in Equation 17 can be defined as

$$NFI = \sum_{i} hw_h + rw.$$

We cannot model *hw* and *rw* endogenously, because they are determined by the workings of the global economy and our model is only for a single country. These two variables (and hence *NFI*) are therefore exogenous in the model. The current account balance *CA* may not be equal to *NFI* if there is a trade surplus or deficit observed in the country's data. When *CA* is greater (less) than *NFI,* the country runs a trade surplus (deficit), and total exports are greater (less) than total imports plus *NFI.* For the external account, the first closure rule is to treat the current account balance *CA* as an exogenous variable, thus controlling its effect on the macroeconomic behavior of the model. For a given level of *CA,* the level of total exports and imports can change, but they have to change simultaneously. For example, CGE models are often used to simulate trade liberalization. Reducing import tariffs affects relative prices for different commodities, which in turn affects imports and exports at the sector and national levels. In this case, total imports usually increase at a given *CA,* which then affects relative prices and exports at the sector level. At the national level, total exports have to increase in response to rising imports to maintain *CA.*

The choice of current account closure influences how we select the second closure rule, which is the identity on the right-hand side of Equation 17. By fixing *CA,* we are also fixing the value of ΔNFA, which means that either total savings *S* or total investment *I* (but not both) should be determined exogenously. We call this choice the "savings–investment" closure, which is a term borrowed from macroeconomics. If the CGE model is savings driven, then *I* is automatically determined by the level of total available savings (that is, $I = S - \Delta NFA$). Consistent with Equation 1, in which *s* is a fixed parameter, our model specification is savings driven. Finally, our treatment of the government balance in Equation 15′ is in fact the third closure rule in the model. We choose to make recurrent consumption spending *G* exogenous and allow the fiscal balance *FB* to adjust to changes in revenues *R.*

Through the introduction of the government, investment demand, and macroeconomic closures, we have included five new equations into the model (Equations 14–18) and five new endogenous variables (*R, FB, N, I,* and *S*).[5] Together, the 18 equations and variables describe a static single-country model. Our current account closure fixes the national trade balance. The government closure implies that changes in revenues alter the fiscal balance (and hence public investment). In our savings-driven closure, total investment adjusts to match total savings. To determine the lasting consequences of changing investment levels, we have to introduce dynamics into the model.

Recursive Dynamics

Most CGE models are essentially static in nature. As mentioned earlier, consumers' demands are derived from a one-period utility function. Saving rates are not endogenously determined by an intertemporal utility function, and so they are not used to smooth consumption over time. Investment and capital accumulation rates are therefore not intertemporally determined either. Rather, the dynamics in our CGE model is defined as a recursive process. Thus, we can completely separate the model into within-period and between-period components.[6] The equations presented above fully specify the within-period component, in which consumers and producers maximize their utility and profits based on prevailing factor and product prices (that is, without forward-looking expectations). Then, between periods, certain exogenous variables in the static model are updated based on either externally determined trends or previous period results. We describe these two kinds of updating procedures in turn.

Various external trends are imposed on the model. Although not shown in Equations 1–18, each variable in the model has a time subscript associated with it. The two most important trends are changes in factor supplies (a proxy for population) and productivity, which are represented by *VS* in Equation 11 and Λ in Equation 2. The first two dynamic equations update these exogenous variables:

$$\overline{VS}_{ft+1} = \overline{VS}_{ft}(1 + gv_{ft}), \text{ where } f \neq k \tag{19}$$

$$\Lambda_{it+1} = \Lambda_{it}(1 + gp_{it}) \tag{20}$$

$$G_{it+1} = G_{it}(1 + gg_{it}), \tag{21}$$

where t is the time subscript in the simulation period (for example, years), k is a subset of f containing the capital factor, gv is the change in supply for factor f in period t, gg is the rate of change in recurrent government spending, and gp is the change in sector i's production function's shift parameter (that is, TFP) in period t. Capital supply is excluded from Equation 19, because, as discussed below, it is based on previous period results. Population growth enters the model via changes in labor supply. However, with nonunitary income elasticities (that is, unequal marginal and average budget shares), consumer demand in Equation 1 must be respecified in per capita terms. Equation 21 shows how government consumption spending G is updated every period based on exogenous trends in is the rate of change in recurrent government recurrent spending gg. All other parameters in the model are fixed values. These include, for example, tax or saving rates (*ty, s,* respectively), share parameters (β), and foreign transfers (*FS, hw,* and *rw*).

Between-period updating may also be based on results from the previous period. Sectoral capital accumulation rates are endogenously determined in the model based on investment levels from the previous period. The amount of new capital is determined by dividing total investment *I* by the capital goods price. This amount is added to existing capital stocks after adjusting for depreciation. Assuming only a single type of capital that is mobile across sectors, as in the model specified above, then the following equation captures the capital accumulation process:

$$VS_{kt+1} = (1 - d)VS_{kt} + \frac{I_t}{PK_t}, \text{ where } PK_t = \sum_i P_{it}\varepsilon_i, \tag{22}$$

where *d* is the national depreciation rate, *PK* is the capital goods price, and ε is the value share for each good *i* in the total investment basket from Equation 16. Because *k* is mobile, new capital is allocated endogenously to equilibrate capital returns across sectors.

In reality, capital is not as mobile as other factors, such as labor, and so we make it immobile across sectors after it has been invested. This assumption implies that the returns on capital in each sector no longer have to be equal. We therefore attach a sector-specific distortion term *Z* in front of the economy-wide factor return variable *W* in Equations 3, 12, and 14. Equation 3 is now replaced by

$$V_{if} = \Lambda_i^{-\frac{\rho_i}{1+\rho_i}} \cdot X_i \left(\alpha_{if} \cdot \frac{PV_i}{Z_{if} \cdot W_f}\right)^{1/(1+\rho_i)}, \text{ for } f = k, \tag{3'}$$

where *Z* is an adjustment factor ($0 < Z < \infty$) and is initially set equal to one. An increase in capital demand in a sector causes *Z* to rise above one, and vice versa. Similarly, we replace Equation 22 with a capital stock updating equation defined at the sector level (that is, in terms of *V* instead of *VS*):[7]

$$V_{ikt+1} = (1 - d)V_{ikt} + SK_{ikt} \cdot \frac{I_t}{PK_t}. \tag{22'}$$

The term *SK* in Equation 22′ is the new capital allocation parameter ($0 < SK < 1$) and specifies how much investment is directed toward each sector. The sum of the *SK* factors therefore equals one. We follow the approach of Dervis, de Melo, and Robinson (1982) by defining *SK* as:

$$SK_{ikt} = SP_{ikt} + \omega \cdot SP_{ikt} \left(\frac{SR_{ikt} - AR_t}{AR_t} \right), \tag{23}$$

where SP is the current sectoral share in aggregate profits, SR is the sectoral profit rate (equal to $Z_{if}W_f$), AR is the economywide average profit rate, and ω is an investment mobility parameter. In this simple specification, new capital is allocated in proportion to each sector's share in aggregate capital income, adjusted by the sector's profit rate relative to the average profit rate.[8] Sectors with higher than average profit rates receive a larger share of investible funds than their share in aggregate profits. Note that the specification in Equation 23 allows us to drop the assumption of only a single type of capital in the set F. This investment allocation procedure is known as a "putty-clay" specification, because new capital is mobile, but once invested it becomes sector specific. More detailed descriptions of the model parameters, variables, and equations can be found in Tables 2A.1 and 2A.2.

The above discussion presents our core CGE model. In summary, the CGE model describes the interactions of various agents, such as households, producers, and the government, in a market-based economy. We capture sectors' technologies via input coefficients, and we allow these to adapt to relative price movements by allowing imperfect substitution in the production and trade functions. While capturing the structure and behavior of individual representative households, we maintain the macroconsistency of microlevel decisionmaking through our general equilibrium framework. The next two sections summarize the model specification in more accessible language and then describe how it is calibrated to empirical data. However, we conclude this subsection by describing some features of the model that were not shown in the above equations.

Regional Production and Marketing Costs

We extend the core CGE model described above in two areas.[9] First, we introduce marketing margins or transaction costs into the model, so that there is a wedge between producer prices PP and market prices P. These transaction costs are imposed on domestic, exported, and imported goods, and they generate demand for the domestic trade and transport services sectors (see Lofgren, Harris, and Robinson 2001).

Second, we disaggregate production across subnational regions (that is, the variables X, Z, PP, and V have regional subscripts). All regional producers have their own production functions and technology coefficients, and they often use region-specific factors, such as agricultural land and farm labor. All regional producers supply their output to a national product market, which avoids having to model interregional trade flows that are usually difficult to measure. Output from each region is combined into a composite national good using a CES aggregation function. Although a single national price exists for each commodity, producers may incur region-specific transaction costs when supplying the national market. Producer prices therefore vary across regions. We also disaggregate households by region, although this is done by calibration rather than by the use of regional subscripts.

These two extensions to the core model allow us to reflect spatial heterogeneity in geographic conditions and marketing constraints. These considerations are important for developing countries, where markets are often underdeveloped, and for agriculture, which depends on agroecological and climatic conditions.

Calibrating the Model to Country Data

One of the main advantages of CGE models over (more complex) theoretical models is their calibration to detailed empirical data. "Calibration" refers to the process of assigning values to the model's parameters and variables, typically using observed country data. Some of the assumptions made when specifying the CGE model were done to ease its calibration, because in many cases the data needed for more complex functional forms are unavailable in developing countries. For example, the LES function used to determine consumer demand assumes that income elasticities remain constant. More elaborate functions often drop this assumption, such as in the "almost ideal demand system." However, we retain the LES function, because it requires data that can readily be obtained from household surveys (for example, expenditure shares and income elasticities). Calibrating the behavior of more complicated functional forms often just involves making more assumptions where data are unavailable. This section describes the data sources and estimation procedures used to calibrate our CGE models.

Social Accounting Matrixes

The values of almost all variables and parameters in the CGE model are drawn from a social accounting matrix (SAM).[10] Constructing a SAM is therefore a fundamental part of developing a CGE model. A SAM is an economywide representation of a country's economic structure. It captures all income and expenditure flows among producers, consumers, the government, and the rest of the world during a particular year. Table 2.1 presents the structure of a SAM that could be used to calibrate the core model described above. The SAM contains a number of "accounts" representing different agents in the model, including sectors (producers) and households (consumers). The rows and columns of the SAM represent incomes and payments, respectively, from one account to another. As with double-entry accounting, the SAM is a consistent economywide database, because row and column totals must be equal. In other words, a payment from one account always becomes an income for another. The SAM therefore provides the base-year equilibrium state for the CGE model.

Table 2.1—General structure of a social accounting matrix

Account	Sectors	Products	Factors	Households	Government	Investment	Rest of world	Total
Sectors		Marketed supply (PD, D)					Export demand (PE, E)[a]	
Products	Intermediate demand (io)[b]			Private consumption (C)[c]	Public consumption (G)[b,d]	Investment demand (N, ε)[b]		Total demand
Factors	Value-added (V, W, Z)[c]							Factor income
Households			Income distribution (δ)[c]				Transfers (hw)[c,e]	Household income (Y)
Government	Indirect tax (te)[a,d]	Indirect tax (tc, tm)[a,d]	Factor tax (tf)[d]	Income tax (ty)[c,d]			Transfers (rw)[d,e]	Total revenues (R)
Savings				Private savings (s)[c]	Public savings (FB)[d]		Foreign savings (FS)[e]	Total savings (S)
Rest of world		Import supply (PM, M)[a]						Total foreign payments
Total	Gross output (PP, X)	Total supply (P, Q)	Factor payments	Total household spending	Recurrent spending	Total investment (I)	Total foreign receipts	

Source: Authors.

[a]Main data sources used are national accounts and regional production data.
[b]Main data sources used are input–output tables and industrial surveys.
[c]Main data sources used are household and labor force surveys.
[d]Main data sources used are government budgets.
[e]Main data sources used are balance of payments information.

A SAM is constructed in two stages. During the first stage, data from different sources are entered into each of the SAM's cells. As with the CGE model, the SAM allows for multiple sectors and households. Thus, the sector, product, and household rows and columns actually contain many subaccounts. The three main data sources for constructing a SAM are national accounts, input–output tables (or supply–use tables), and nationally representative household budget surveys. As shown in Table 2.1, national accounts provide information on the composition of GDP at factor cost (that is, sectoral value-added) and by broad expenditure groups at market prices (for example, $C+I+G+E-M$). The technical coefficients in the input–output table are used to estimate intermediate demand based on sectors' levels of GDP or gross output. It also disaggregates government and investment demand across products. The household survey is used to segment labor markets (that is, disaggregate labor income into different groups, such as by education). The survey also defines households' expenditure patterns and the distribution of factor incomes to representative household groups. The survey data are therefore the main determinant of differential income and distributional effects across household groups in the CGE model.

Other databases are used to complete specific cells in the SAM. Government budgets provide information on tax rates, revenues, and expenditures. Although not shown in the table, government budgets (and household surveys) also determine the level and distribution of social transfers. Customs and revenue authorities provide data on imports and exports and their associated tariffs and subsidies. The balance of payments, usually compiled by a country's central bank, is used to populate the external or "rest of world" account, including information on transfer receipts and payments and the current account balance. Finally, sectors in our SAMs are usually disaggregated across subnational regions using information on regional production and technologies from agricultural and industrial surveys. Trade margins, which are not shown in the table, are estimated using information on producer and consumer prices. Trade margins may also be drawn from input–output or supply–use tables.

There are inevitably inconsistencies between data from different sources, which lead to unequal row and column totals in our SAMs. The second stage of constructing a SAM is therefore to balance these totals. This reconciliation of data from disparate sources is similar to a rebasing of national accounts. We use cross-entropy econometric techniques to estimate a balanced SAM (see Robinson, Cattaneo, and El-Said 2001). This procedure is a Bayesian approach that uses a cross-entropy distance measure to minimize the deviation in the balanced SAM from the unbalanced SAM containing the original data. Constraints are imposed during the estimation procedure to reflect narrower confidence intervals around better-known control totals (for example, total GDP). Table 2.1 shows which cell entries in the balanced SAM are used to calibrate the model's variables and parameters. From this table it is clear that the SAM and its underlying data sources provide almost all the information needed to calibrate the CGE model. Only the behavioral elasticities remain (β, ρ, θ, and φ).

Behavioral Elasticities and Other External Data

Behavioral elasticities are needed for the consumption, production, and trade functions. The LES demand function requires information on income elasticities and the Frisch parameter (see Frisch 1959). We econometrically estimate income elasticities using the same household survey data on which the SAM is built, following the approach described in King and Byerlee (1978). Marginal budget shares (β in Equation 1) are derived by combining the estimated income elasticities with the average budget shares drawn directly from the SAM.

Trade elasticities determine how responsive producers and consumers are to changes in relative prices when deciding to supply goods to or purchase goods from foreign markets. Higher elasticities are expected when substituting between more homogenous products, such as maize and copper. Lower elasticities are expected for more differentiated product categories, such as chemicals and machinery. In most developing countries the data needed to econometrically estimate country-specific elasticities do not exist—not, at least, in an appropriate form (see Arndt, Robinson, and Tarp 2002). We therefore assign values to our two trade elasticities (θ and φ in Equations 5 and 7) using global estimates from Dimaranan (2006).

The elasticities governing factor substitution in the production functions (ρ in Equation 2) rarely exist for developing countries. In the absence of reliable country-specific estimates, we assume elastic factor substitution for most activities (that is, $\sigma > 1$: σ is a transformation of ρ). This assumption is consistent with recent meta-analyses of econometrically estimated elasticities (see, for example, Boys and Florax 2008) and cross-country econometric analysis (see Behar 2009).

Finally, the SAM provides information on values but not on quantities. We therefore use external data sources to calibrate the model's production output X and factor quantities V. For example, crops' land use and gross output are calibrated to match agricultural data on harvested area (in hectares) and production quantities (in metric tons). Observed labor employment numbers are also used to determine sector-specific wages (Z in Equation 3′). In such cases, factor and product prices in the model are not normalized to one, but rather reflect observed prices.

Baseline Dynamics

The model is calibrated to the base year reflected in the SAM. It is then run forward over time to create a baseline growth path—normally a series of years. The baseline scenario is therefore determined by annual growth in factor supplies and productivity. The growth rates of factor supplies (apart from capital) and productivity are calibrated to observed historical trends. For example, changes in labor supply are usually based on population projections for rural and urban areas and on labor force participation rates for workers with different education levels. Similarly, agricultural land either expands alongside rural population or is calibrated to long-term trends in total harvested land area from historical data. The annual growth capital stocks are targeted so that they grow at a relatively smooth rate in relation to GDP. This is done either by assigning base-year capital–output ratios or by adjusting the price of capital *PK*.

After a suitable baseline scenario has been calibrated, it is possible to conduct counterfactual simulations. Alternative growth paths are evaluated by changing exogenous variables in the model from baseline levels. The model is re-solved, and deviations from the baseline are attributed to the simulated change in policies or external factors. The model is therefore an ideal tool for ex ante evaluation of development options in countries where historical evidence is lacking and ex post analysis is impossible. Even though the model's general equilibrium specification is based on economic theory, its detailed calibration to observed data provides a quasi-empirical laboratory for conducting complex experiments within a consistent modeling framework.

Linking to Poverty and Nutrition Modules

The household survey provides detailed information on the income and expenditure flows of individual respondents. Some of this information is lost when it is aggregated into representative households in the CGE model. To retain as much information as possible, we link each representative household in the model to its corresponding household in the survey. Changes in household consumption quantities in the model are passed down to the survey and used to update the consumption levels of corresponding respondents:

$$HH_{ist}^{h} = HH_{ist-1}^{h} \cdot \frac{C_{iht}}{C_{iht-1}}, \text{ where } g{:}\, s \rightarrow h, \tag{24}$$

where s is the survey's detailed household, C is the quantity of aggregate commodity i consumed by representative household h in the model (see Equation 1), and HH is the quantity of detailed commodity i consumed by household s in the survey. g represents the mapping relationship between survey's detailed households and the more aggregate households in the CGE model (a many-to-one mapping). Equation 24 shows how annual consumption changes in the model cause proportional changes for corresponding survey households. We therefore assume that all survey households in a group experience the same proportional change in consumption. However, the different consumption patterns of survey households mean that changes in total consumption levels will vary across households in each group:

$$HT_s = \sum_i (HH_{is} \cdot ps_{is}), \tag{25}$$

where *HT* is total consumption of the survey household *s* and *ps* is the price of commodity *i* paid by household *s*. We fix *ps* at base-year levels (or normalize it to one if price and quantity data are not identified separately in the survey), so that *HT* reflects real consumption changes. We compare HT to base-year poverty lines to determine whether a survey household is classified as poor or nonpoor in each time period and simulation. From this we can calculate standard poverty measures.[11] Our poverty module is top-down: we do not impose consistency in absolute consumption changes between the CGE model and the microsimulation module. It is also expenditure based, because consumption changes rather than factor income changes are passed down to the survey.[12]

A similar top-down approach is used to estimate changes in households' nutritional status. Consumption quantity data from the household survey is combined with calorie tables to calculate initial caloric availability. As with Equations 24 and 25, model results on changes in food consumption quantities are then applied to the survey data to estimate changes in total household caloric availability adjusted by adult equivalence scales (see UNU, WHO, and FAO 2004). This measure is compared to a "malnutrition line" to determine changes in calorie-deficiency rates for each time period and simulation. The nutrition module retains the detailed information in the household survey and accounts for size and demographic structure when determining the minimum number of calories required by each household.

Summary of the Model

As discussed in this chapter, an important factor determining the contribution of sectors to economywide growth is their linkages to the rest of the economy. For example, agriculture's proponents argue that agriculture has strong growth linkages. Both consumption (forward) and production (backward) linkages are captured in our CGE model, whose nested CES production functions allow producers to generate demand for both factors and intermediates when maximizing profits. To reflect the heterogeneity of producers, our models are calibrated to detailed SAMs that distinguish among multiple sectors, regions, and products. Products are traded within national markets (that is, the model does not capture trade flows among subnational regions). The CGE model identifies multiple types of factors, including capital, labor, and cropland. Land and labor are usually disaggregated across skill groups and subnational regions. Both land and labor can be reallocated or migrate across sectors in response to endogenously determined factor demands. In contrast, capital is immobile and earns sector- or region-specific returns. This detailed specification of production and factor markets in our model allows us to capture the changing scale and technology of production across sectors and subnational regions, and therefore can demonstrate how changes in the structure of growth will influence a country's distribution of incomes and household poverty.

The contribution of different sectors to economic growth is influenced by international trade. For example, some development specialists are skeptical about agriculture's role in development. They suggest that import competition has undermined agriculture's growth linkages and that the availability of food imports reduces the need for investment in domestic agriculture. Furthermore, in agriculture, there are greater market opportunities for export crops than for food staples. Our CGE model captures both import competition and export opportunities by allowing producers and consumers to shift between domestic and foreign markets, depending on changes in the relative prices of imports, exports, and domestic goods. More specifically, the decision by producers to supply domestic or foreign markets is governed by CET functions, whereas the decision to purchase domestically produced or imported products is determined by CES functions. In this way the CGE model captures how import competition and the changing export opportunities of different sectors can strengthen or weaken the linkage between their economic growth and the resultant poverty reduction.

The relative importance of sectors in improving household livelihoods may vary considerably. Income and expenditure patterns differ across households, especially across subnational regions and rural and urban areas. These differences are important for distributional change, because the incomes generated by different sectors will accrue to different households, depending on their location and factor endowments. To capture this process, the CGE model distinguishes among various representative households, each of which is an aggregation of a group of households in nationally representative household surveys. Households in the model earn incomes through the employment of their factors of production; they then pay taxes, save, and make transfers to other households. Each household uses its remaining income to consume commodities under an LES demand system. To retain as much information on households' income and expenditure patterns as possible, the CGE model is linked to a microsimulation module based on a national household survey. Changes in commodity consumption for each aggregate household group in the

CGE model are used to adjust the commodity-level expenditures of corresponding households in the survey. Real consumption levels are then recalculated in the survey, and standard poverty measures are re-estimated using the revised consumption measure.

The CGE model makes several assumptions about how the overall economy maintains macroeconomic balance. These closure rules concern the current account, the government's fiscal balance, and the savings or investment account. We essentially assume that a real exchange rate adjusts to maintain a fixed current account balance. Thus, our model countries cannot increase foreign borrowing but have to generate export earnings to finance imports. Although this assumption realistically limits the degree of import competition in the domestic market, it also underlines the importance of export-oriented sectors, such as high-value agriculture. For the government account, tax rates and consumption expenditures are determined exogenously, leaving the fiscal balance to adjust to ensure that public revenue equals spending. Finally, we assume that total investment adjusts to changes in national savings under a closure rule for savings-driven investment. These final two closures allow the model to capture the negative crowding-out effects of falling government revenues when the structure of growth shifts toward lower tax-paying sectors, such as traditional agriculture.

The CGE model is recursive dynamic, which means that certain parameters are updated between periods based on historical trends or results from the previous period. Our models are generally run for 10–15 years, with each equilibrium period representing a single year. During this time the model captures exogenous demographic and technological changes. Changes in the population, labor supply, human capital, and TFP are drawn from historical trends. Capital accumulation is determined endogenously, with previous-period investment generating new capital stock. Although the allocation of new capital is influenced by sectors' or regions' current shares of gross operating surplus, the final allocation depends on depreciation and relative profitability. Sectors generating above-average returns in the previous period will receive a larger share of new capital in the current period.

In summary, the CGE model incorporates distributional change by (1) disaggregating growth across sectors and subnational regions, (2) capturing employment effects through factor markets and price effects through product markets, and (3) translating these two effects onto each household in the survey according to the household's unique factor endowment and income and expenditure patterns. The structure of the growth–poverty relationship is therefore defined explicitly ex ante based on observed country-specific structures and behavior. This definition allows for the model to capture and contrast the distributional outcomes associated with economic growth in different sectors.

Limitations of the Model

Data Constraints

Even though CGE models address some of the limitations of other ex ante modeling approaches, they are not without their own limitations. To begin with, they are very data intensive, which is perhaps the most common criticism lodged against CGE models. To calibrate the model, it is necessary to construct a SAM, which draws together information from a wide range of data sources. Often these data are inconsistent and are imprecisely measured. This problem is obviously a constraint for most methodologies. However, the process of reconciling a SAM inevitably causes damage to all data sources. Without knowing the relative merits of each source, it is impossible to determine whether important information is lost in the SAM estimation process. Because most parameter values for CGE models are drawn from SAMs and economic structure is a key determinant of simulation results, low-quality data and poor SAM estimation procedures can greatly undermine the empirical strength of CGE analysis.

Data concerns are almost impossible to fully address, because errors exist in every economic instrument or measure. Moreover, data on developing countries are often of lower quality than elsewhere, which further complicates attempts to accurately calibrate CGE models. Even though these concerns are far from solved, Africa's data problem is becoming less severe with time. Data availability has improved considerably, primarily because of more frequent and better designed and implemented household surveys. Household surveys have also helped to strengthen national accounting procedures. Moreover, methods to reconcile data sources and estimate SAMs have improved, thanks in large part to cross-entropy techniques (see Robinson, Cattaneo, and El-Said 2001) and to more standardized approaches.

Unfortunately, there has been less progress in estimating the behavioral elasticities of CGE models. One positive trend is that income elasticities can now be more readily estimated from household surveys. However, these elasticities are less crucial for determining model results (see Sadoulet and De Janvry 1995). A more important constraint is the lack of country-specific trade elasticities. Most studies are forced to use cross-country estimates from the literature or estimates from other countries (hopefully from countries with similar initial conditions). We are forced to adopt this approach, primarily because long time-series trade data (needed to estimate elasticities) do not exist for most African countries.

Closure Rules

Ensuring macroconsistency in CGE models requires assumptions or closure rules that can influence the functioning and results of a model. Many researchers argue that the importance of closures in determining simulation results implies that CGE models are too sensitive to be used for economic analysis, especially for making policy prescriptions. However, this concern is often overstated. Macroclosures are usually chosen based on knowledge of a particular country's macroeconomy. For example, a flexible real exchange rate is appropriate in most eastern and southern African countries, where exchanges are allowed to float. In contrast, a fixed exchange rate closure rule might be more appropriate for those west African countries that share a common currency. The choice of macroclosure may therefore prove to be a feature rather than a constraint of CGE models. In other words, it is part of the simulation design. For this reason, it is essential that closure rules be made explicit, as we have done in this chapter.

CGE models capture factor markets and resource constraints. However, these factor markets also have closure rules; that is, we have to select variables to equate factor demand and supply. By default, we assume that land and labor are fully employed and that wages adjust to clear markets (see Fields 2009). This decision was motivated by rural labor shortages during planting and harvesting periods and by shortages of higher skilled labor in most African countries. However, un- and underemployed labor may exist in some developing countries. Allowing for slack resources would increase growth outcomes in the CGE model. By adopting a full-employment closure rule, we are also assuming that labor markets are functioning and that wages do indeed adjust to equate demand and supply. The existence of slack labor introduces rigidity into wage movements, because surplus labor competes and prevents wages from rising in response to increased labor demand. In the case of Africa, the choice of labor market closure depends on whether the model needs to capture labor shortages during the cropping season or slack labor available to the nonfarm economy. In our case, rather than assume slack labor, we model economic growth though increases in TFP. We also introduce rigidities into factor markets by segmenting labor markets by skill, land by region, and capital by sector. We also introduce intersectoral wage differentials.

Coverage and Detail

Single-country CGE models usually make the small-country assumption that world prices are fixed. In contrast, global CGE and multimarket models explicitly model production in other countries as well as the trade flows among them (see Hertel 1997; Rosegrant et al. 2008). World prices are therefore endogenous in these models. Assuming fixed world prices is problematic when modeling large developing countries whose production decisions may have global implications. In our African context, the small-country assumption is less problematic, because African countries typically play only minor roles in the global economy. A hybrid approach is possible, in which global and country-level models are linked top down. Changes in world prices and export demand from the global model are imposed on country-level models (see Arndt and Thurlow 2010). This approach retains coverage of global models, as well as the more detailed structure of country models. However, this is unnecessary for our purposes, given our focus on domestic sources of growth and poverty reduction.

Country CGE models capture detailed macro- and microlevel aspects of the economy. However, this approach typically requires adopting simpler specifications than those required by more specialized models. For example, farm models often reflect the fact that households' production and consumption decisions are non-separable, whereas our CGE model assumes separability (see Lofgren and Robinson 1999). Similarly, commodities in multimarket models are usually more disaggregated, because they do not require information on microlevel production technologies. Our CGE model sacrifices such detail to capture general equilibrium effects.

In summary, all models suffer limitations. Ultimately the choice of which model to use depends on the issues or questions being addressed. In this chapter we have developed a CGE model that can appropriately be used to examine the growth and poverty implications of alternative sectoral growth strategies in low-income African countries. The same core CGE model is used in each case study chapter in this volume. Each chapter describes the country-specific data used to calibrate the core model. Thus, any differences in outcomes across case studies are primarily due to differences in each country's unique economic structure and growth prospects.

Appendix

Table 2A.1—Full dynamic computable general equilibrium model variables and parameters

Index subscripts			
i or j	Sectors and products; *J* is the sectoral and commodity set	*r*	Subnational regions
f	Factors; *F* is the factor's set	*t*	Time periods
h	Households; *H* is the household's set		
Endogenous variables			
AR	Average economywide capital rental rate	*PM*	Import price
C	Household consumption quantity	*PP*	Producer price
CPI	Consumer price index*	*PS*	Supply price (without transaction costs)
D	Domestic production supplied to local market	*PT*	Total domestic supply price (all regions)
E	Export quantity	*PV*	Value-added price
ER	Nominal exchange rate	*Q*	Composite commodity supply (with imports)
FB	Recurrent fiscal balance	*R*	Government tax revenues
FS	Foreign savings (capital inflows)*	*SK*	Sectoral allocation of new capital
G	Government consumption quantity*	*SP*	Sectoral profit share
I	Total investment spending	*SR*	Sectoral return on capital
L	Transaction cost demand quantity	*T*	Total domestic supply quantity (all regions)
M	Import quantity	*V*	Factor demand
N	Investment demand for sectoral goods	$\overline{VS}$	Total factor supply*
P	Market price	*X*	Gross output (by region)
PD	Domestic price (with transaction costs)	*Y*	Total household income
PE	Export price	*Z*	Wage distortion term
PK	Capital price		
Exogenous variables			
cd	Marketing margin on domestic products	Γ	Export function shift parameter
ce	Marketing margin on exports	Λ	Production function shift parameter
cm	Marketing margin on imports	Φ	Region aggregation function shift parameter
d	Economywide capital depreciation rate	Ω	Import function shift parameter
gg	Government consumption growth rate	α	Production function share parameter
gp	Total factor productivity growth rate	β	Household marginal budget share
gv	Total factor supply growth rate	γ	Non-income-related consumption quantity
hw	Household foreign transfer receipts	δ	Factor income distribution shares
io	Input coefficient matrix	ε	Investment demand value shares
pwe	World export price	θ	Import substitution elasticity transformation
pwm	World import price	κ	Consumer price index weights
rw	Government foreign transfer receipts	μ	Import function share parameter
s	Marginal savings rates	ν	Region substitution elasticity transformation
tc	Commodity sales tax rate	ρ	Factor substitution elasticity transformation
te	Export tax rate	τ	Export function share parameter
tf	Factor tax rate (for example, corporate tax)	ϕ	Export substitution elasticity transformation
tm	Import tariff rate	ψ	Region aggregation function share parameter
ty	Direct income tax rate	ω	New investment mobility parameter

Source: Authors.
*Denotes fixed by closure.

Table 2A.2—Full dynamic computable general equilibrium model equations

$PM_{it} = ER_t(1 + tm_i)pwm_i + \sum_j P_{jt}cm_{ji}$	A1
$PE_{it} = ER_t(1 - te_i)pwe_i + \sum_j P_{jt}ce_{ji}$	A2
$(1 - tc_i)P_{it}Q_{it} = PD_{it}D_{it} + PM_{it}M_{it}$	A3
$PD_{it} = PS_{it} + \sum_j P_{jt}cd_{ji}$	A4
$PT_{it}T_{it} = PS_{it}D_{it} + PE_{it}E_{it}$	A5
$PP_{irt} = PV_{irt} + \sum_j P_{jt}io_{jir}$	A6
$X_{irt} = \Lambda_{irt}\left(\sum_f a_{irf}V_{irft}^{-\rho_{ir}}\right)^{-1/\rho_{ir}}$	A7
$V_{irft} = \Lambda_{irt}^{-\frac{\rho_i}{1+\rho_{ir}}} X_{irt}\left(a_{if}\dfrac{PV_{irt}}{Z_{irft}W_{ft}}\right)^{1/(1+\rho_{ir})}$	A8
$T_{it} = \Phi_{it}\left(\sum_r \Psi_{if}X_{irt}^{-\nu_i}\right)^{-1/\nu_i}$	A9
$X_{irt} = \Phi_{it}^{-\frac{\nu_i}{1+\nu_i}} T_{it}\left(\Psi_{if}\dfrac{PT_{it}}{PP_{irt}}\right)^{1/(1+\nu_i)}$	A10
$T_{it} = \Gamma_i[\tau_i D_{it}^{\varphi_i} + (1 + \tau_i)E_{it}^{\varphi_i}]^{1/\varphi_i}$	A11
$\dfrac{D_{it}}{E_{it}} = \left(\dfrac{\tau_i}{1 - \tau_i} \cdot \dfrac{PD_{it}}{PE_{it}}\right)^{1/(\varphi_i - 1)}$	A12
$Q_{it} = \Omega_i\left[\mu_i D_{it}^{-\theta_i} + (1 + \mu_i)M_{it}^{-\theta_i}\right]^{-1/\varphi_i}$	A13
$\dfrac{D_{it}}{M_{it}} = \left(\dfrac{\mu_i}{1 - \mu_i} \cdot \dfrac{PM_{it}}{PD_{it}}\right)^{1/(1+\varphi_i)}$	A14
$L_{it} = \sum_j (cd_{ji}D_{jt} + ce_{ji}E_{jt} + cm_{ji}M_{jt})$	A15
$Y_{ht} = \sum_{irf} \delta_{hf}(1 - tf_f)Z_{irft}W_{ft}V_{irft} + hw_h ER_t$	A16
$C_{hi} = \beta_{hi}\left[(1 - s_h - ty_h)Y_{ht} - \sum_j P_{jt}\gamma_{hj}\right]P_{it}^{-1} + \gamma_{hi}$	A17
$R_t = \sum_i (tc_i P_{it}Q_{it} + tm_i pwm_i M_{it} + te_i pwe_i E_{it}) + \sum_h ty_h Y_{ht} + \sum_{irf} tf_f Z_{irft}W_{ft}V_{irft}$	A18
$R_t + ER_t rw = \sum_i P_{it}G_{it} + FB_t$	A19

(*continued*)

Table 2A.2—Continued

$I_t = \sum_h s_h Y_{ht} + FB_t + ER_t FS$	A20
$I_t \varepsilon_i = P_{it} N_{it}$	A21
$\sum_{ir} V_{irft} = \overline{VS}_{ft}$	A22
$Q_{it} = \sum_h C_{iht} + N_{it} + G_{it} + \sum_j io_{ji} X_{it} + L_{it}$	A23
$\overline{FS} + \sum_h hw_h + rw = \sum_i pwm_i M_{it} - \sum_i pwe_i E_{it}$	A24
$CPI = \sum_i P_{it} x_i$	A25
$\overline{VS}_{ft+1} = \overline{VS}_{ft}(1 + gv_{ft})$, where $f \neq k$	A26
$\Lambda_{it+1} = \Lambda_{it}(1 + gp_{it})$	A27
$G_{it+1} = G_{it}(1 + gg_{it})$	A28
$V_{irkt+1} = (1-d)V_{irkt} + SK_{irkt}\dfrac{I_t}{PK_t}$, where $PK_t = \sum_i P_{it}\varepsilon_i$	A29
$SK_{irkt} = SP_{irkt} + \omega SP_{irkt}\left(\dfrac{SR_{irkt} - AR_t}{AR_t}\right)$	A30
$SP_{irkt} = Z_{irkt} W_{kt} V_{irkt} + (\sum_{jr'k'} Z_{jr'k't} W_{k't} V_{jr'k't})^{-1}$, where r' and r are exchangeable, and k' and k are exchangeable	A31
$AR_t = \left(\sum_{irk} Z_{irkt} W_{kt} V_{irkt}\right)\left(\sum_{irk} V_{irkt}\right)^{-1}$	A32
$SR_{irkt} = \dfrac{Z_{irkt} W_{kt}}{AR_t}$	A33

Source: authors.

Note: A bar over a variable indicates that its value is either fixed or exogenously adjusted over time.

Notes

1. For a review of different methods, see Sadoulet and De Janvry (1995) and Francois and Reinert (1997).

2. See Diao, Yeldan, and Roe (1998) for a discussion of Ramsey-style intertemporal utility functions and their role in determining consumers' consumption and saving behavior.

3. Given the existence of by-products (that is, multiple goods from a single sector) and the fact that the same good can be produced in different sectors, our model actually distinguishes between sectors (activities) and goods (commodities). However, in this chapter we simplify the exposition by using the two interchangeably.

4. In reality, part of factor incomes (for example, the return to capital) can be owned by the government or foreign institutions. Although this situation is allowed in the model that we actually implement in each case study, at this stage we ignore nonhousehold factor ownership to simplify the discussion.

5. Note that our third closure rule made *G* exogenous in Equation 15.

6. Lofgren, Harris, and Robinson (2001) developed an earlier version of the static component of our CGE model.

7. For mobile factors, *Z* and *VS* remain constant, and *W* and *V* adjust to clear factor markets. For sector-specific factors, such as capital, *W* and *V* are fixed, and *Z* and *VS* are the adjustment variables.

8. The equations defining *SP, SR,* and *AR* are shown in Table 2A.2 in the appendix to this chapter (Equations A31–A33).

9. The full specification of the model is provided in Table 2A.2 in the appendix to this chapter.

10. For detailed discussions of SAMs see, for example, Pyatt and Round (1985) and Reinert and Roland-Holst (1997).

11. Three poverty measures are commonly used in the literature and are also used in this book. The poverty headcount ratio (or "poverty rate" or "incidence" of poverty) is the proportion of the population with per capita consumption below the poverty line. The poverty gap (or "depth" of poverty) is the extent, measured as a proportion of the poverty line, to which a given group of poor people's consumption level falls below the poverty line. The squared poverty gap (or "severity" of poverty) is the average of the squared values of the poverty gaps for different groups of poor people (see Foster, Greer, and Thorbecke, 1984, for details).

12. For income-based microsimulation modules with occupational choice, see Cogneau, Grimm, and Robilliard (2003) and Cogneau and Robilliard (2007).

References

Armington, P. A. 1969. "A Theory of Demand for Products Distinguished by Place of Production." *IMF Staff Papers* 16 (1): 159–178.

Arndt, C., and J. Thurlow. 2010. "Mozambique." In *Agricultural Price Distortions, Inequality and Poverty,* edited by K. Anderson, J. Cockburn, and W. Martin, 303–329. Washington, DC: World Bank.

Arndt, C., S. Robinson, and F. Tarp. 2002. "Parameter Estimation for a Computable General Equilibrium Model: A Maximum Entropy Approach." *Economic Modelling* 19: 375–398.

Behar, A. 2009. *Direct Technical Change, the Elasticity of Substitution and Wage Inequality in Developing Countries.* Discussion paper 467. Oxford, UK: Department of Economics, University of Oxford.

Boys, K. A., and R. J. G. M. Florax. 2008. "Meta-Regression Estimates for CGE Models: Input Substitution Elasticities in Production Agriculture." Paper presented at the Eleventh Annual Conference on Global Economic Analysis, Helsinki, Finland, June 12–14.

Cogneau, D., and A. S. Robilliard. 2007. "Growth, Distribution and Poverty in Madagascar: Learning from a Microsimulation Model in a General Equilibrium Framework." In *Microsimulation as a*

Tool for the Evaluation of Public Policies: Methods and Applications, edited by A. Spadaro, 73–110. Bilbao, Spain: Fundación BBVA.

Cogneau, D., M. Grimm, and A. S. Robilliard. 2003. "Evaluating Poverty Reduction Policies: The Contribution of Micro-Simulation Technique." In *New International Poverty Reduction Strategies,* edited by J. P. Cling, M. Razafindrakato, and F. Roubaud, 340–370. London: Routledge.

Deaton, A. 2005. "Measuring Poverty in a Growing World (or Measuring Growth in a Poor World)." *Review of Economics and Statistics* 57 (1): 1–19.

Delgado, C., J. Hopkins, and V. A. Kelly. 1998. *Agricultural Growth Linkages in Sub-Saharan Africa.* Research Report 107. Washington, DC: International Food Policy Research Institute.

Dervis, K., J. de Melo, and S. Robinson. 1982. *General Equilibrium Models for Development Policy.* New York: Cambridge University Press.

Diao, X., E. Yeldan, and T. Roe. 1998. "A Simple Dynamic Applied General Equilibrium Model of a Small Open Economy: Transitional Dynamics and Trade Policy." *Journal of Economic Development* 23 (1): 77–101.

Dimaranan, B., ed. 2006. *Global Trade, Assistance, and Production: The GTAP 6 Database.* West Lafayette IN, US: Center for Global Trade Analysis, Purdue University.

Fields, G. S. 2009. "Segmented Labor Market Models in Developing Countries." In *The Oxford Handbook of Philosophy of Economics,* edited by H. Kincaid and D. Ross, 476–510. Oxford, UK: Oxford University Press.

Foster, J., J. Greer, and E. Thorbecke. 1984. "A Class of Decomposable Poverty Measures." *Econometrica* 52 (3): 761–766.

Francois, J. F., and K. A. Reinert, eds. 1997. *Applied Methods for Trade Policy Analysis: A Handbook.* New York: Cambridge University Press.

Frisch, R. 1959. "A Complete Scheme for Computing All Direct and Cross Demand Elasticities in a Model with Many Sectors." *Econometrica* 27 (2): 177–196.

Haggblade, S., J. Hammer, and P. B. R. Hazell. 1991. "Modeling Agricultural Growth Multipliers." *American Journal of Agricultural Economics* 73 (2): 361–374.

Hertel, T. W. 1997. *Global Trade Analysis: Modeling and Applications.* Cambridge, UK: Cambridge University Press.

King, R. P., and D. Byerlee. 1978. "Factor Intensities and Locational Linkages of Rural Consumption Patterns in Sierra Leone." *American Journal of Agricultural Economics* 60 (2): 197–206.

Lofgren, H., and S. Robinson. 1999. "Nonseparable Farm Household Decisions in a Computable General Equilibrium Model." *American Journal of Agricultural Economics* 81 (3): 663–670.

Lofgren, H., R. Harris, and S. Robinson. 2001. *A Standard Computable General Equilibrium (CGE) Model in GAMS.* Microcomputers in Policy Research 5. Washington, DC: International Food Policy Research Institute.

Pyatt, G., and J. I. Round. 1985. *Social Accounting Matrices: A Basis for Planning.* Washington, DC: World Bank.

Ravallion, M. 2003. "Measuring Aggregate Welfare in Developing Countries: How Well Do National Accounts and Surveys Agree?" *Review of Economics and Statistics* 85 (3): 645–652.

Reinert, K. A., and D. W. Roland-Holst. 1997. "Social Accounting Matrices." In *Applied Methods for Trade Policy Analysis: A Handbook,* edited by J. F. Francois and K. A. Reinert. New York: Cambridge University Press.

Robinson, S., A. Cattaneo, and M. El-Said. 2001. "Updating and Estimating a Social Accounting Matrix Using Cross Entropy Methods." *Economic Systems Research* 13 (1): 47–64.

Rosegrant, M. W., C. Ringler, S. Msangi, T. B. Sulser, T. Zhu, and S. A. Cline. 2008. *International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT): Model Description.* Washington, DC: International Food Policy Research Institute.

Sadoulet, E., and A. De Janvry. 1995. *Quantitative Development Policy Analysis.* Baltimore: Johns Hopkins University Press.

Sala-i-Martin, X., and M. Pinkovskiy. 2010. *African Poverty Is Falling . . . Much Faster than You Think!.* Working Paper 15775. Cambridge, MA, US: National Bureau of Economic Research.

UNU, WHO, and FAO (United Nations University, World Health Organization, and Food and Agriculture Organization of the United Nations). 2004. *Human Energy Requirements: Report of a Joint FAO/WHO/UNU Expert Consultation, Rome, October 17–24, 2001.* Food and Nutrition Technical Report Series 1. Rome.