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by

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I. Introduction

The future of tropical rain forests is currently a top issue both in the international political debate and in the resource economics literature. There is a consensus among economists [e. g. Pearce, 1990; Repetto, 1988] that the local externalities of deforestation - e. g. nutrient losses and soil erosion - and the global spillovers - CO_2 emissions and loss of biodiversity- justify internal policy interventions and external financial compensation. Numerous policy proposals for internalizing local externalities have been made [e. g. Muzondo et al., 1990] and several financial compensation schemes have been discussed in the literature.[1] However, there are only few attempts to quantify the effects of policies on deforestation. Nearly all of them have been carried out in a partial equilibrium framework concentrating only at direct policies like land taxes, subsidized credits etc. [e.g. Binswanger, 1989; Mahar, 1989] and ignoring other distortions in the economy.[2] The important question is, however, whether the overall policy package encourages deforestation. Several authors have, therefore, suggested to integrate environmental models into more comprehensive macroeconomic models [e. g. Bojö et. al., 1990; Bolton, 1988; Devarajan, 1990].

Our aim in this paper is to describe the theory of such an extended model, constructed for quantitative analyses of the likely consequences of policies to reduce deforestation. To do this, we take as our reference point a standard computable general equilibrium (CGE) model as described in Dervis et al. [1982] and extend it by a forestry submodel along the lines of Dee [1991 b]. The multisectoral approach allows us to answer the question whether the overall policy environment encourages deforestation. The forestry submodel enables us to examine the conventional forestry policy instruments like resource taxes, secure property rights, selective logging regimes, and the setting-up of national parks. Altogether, the model captures the implications of environmental and economic policy instruments for land use patterns. This is important, because the question of whether the forests should be logged, or left as protected areas, or cleared entirely for agricultural use, is primarily a question of land use patterns.

The plan of the paper is as follows. In chapter II we work through the theoretical structure of the model system. In chapter III we discuss exemplary for Cameroon how the model is specified numerically. Finally, chapter IV contains some concluding remarks.

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1 See Nunnenkamp [1992] for a critical review of financial compensation schemes.

2 The only exceptions, to our knowledge, are the studies by Dee [1991 a] on Indonesia and Thiele, Wiebelt [1992,1993] on Cameroon.

II. Theoretical Structure of the Model

The model to be presented is closely related to previous dynamic CGE models built at the World Bank. The model is Walrasian in the sense that in each period, it determines relative prices that clear markets. Demands and supplies in each market come from the independent optimizing decision of the various agents subject to their budget constraints.

The model departs from CGE models in the Scarf-Shoven-Whalley tradition in that it explicitly features expenditure flows arising from government behavior and the activities of investors. Although government and investors' behavior is modeled in a rudimentary fashion, their inclusion is needed to capture their activities in the economy. The model also departs from previous CGEs in the following respects. First, land is introduced as an additional production factor in agricultural and forestry activities. Second, forestry's production relations are derived from solving an intertemporal harvesting problem common in the resource economics literature. Third, the model introduces a symmetry between the treatment of exports and imports in a single-country model by departing from the assumption of perfect substitutability between commodities produced for the domestic market and for exports.

The model is presented in three stages. First, we provide an overview of the model, distinguishing between the static part and the dynamic part and describing markets, agents in the markets, and functional forms governing agents' behavior (section 1). Second, we describe the equations of the static within-period model (sections 2 to 4). Third, we describe the dynamic processes that drive the model forward in time.

1. Overview

The structure of the model is outlined in Table 1. It consists of two parts. First, there is a static CGE model which solves for a one-year equilibrium. In this part, a set of markets for commodities, factors, and foreign exchange is assumed to clear subject to a variety of structural rigidities and to choices of exogenous variables, including policy variables. Given these constraints, the static equilibrium represents an optimum for producers and consumers. Second, intertemporal linkage equations update exogenous variables and parameters that are dependent on policy choices and specify dynamic processes such as

Table 1 - Main Features of the CGE Model

1. Model dimension: n sectors, some of which are nontraded; one consumer; three primary factors (labor; land; capital; labor differentiated by occupations; land differentiated by soil qualities) with labor mobile, land mobile or immobile, and capital immobile across sectors in the short run

2. Production: cost minimizing producers using CES or Cobb-Douglas production technology for total value added outside forestry and non-land value added in forestry; forestry maximizes the discounted land rental subject to growth characteristics of the forest and Leontief production technology for total non-land inputs; increasing returns to scale in forestry; intermediate requirements involve fixed coefficients across intermediates in all sectors but allow for substitution between domestically produced and imported intermediates within each sector.

3. Final demand: linear expenditure system for single household; fixed coefficient investment demand by origin; fixed coefficient demand by the government; fixed real government consumption; government savings determined residually.

4. Foreign trade: imports and domestically produced goods are imperfect substitutes but have the same marginal rate of substitution in all uses; capital inflows fixed in terms of foreign currency; the real exchange rate defined as the relative price of foreign produced goods in terms of the numeraire (GDP-deflator) clears the market for domestically produced goods; domestic production is supplied for domestic market and for export sales according to a CET transformation function; small country assumption for import supplies; constant elasticity demand function for exports.

5. Equilibrium conditions: supply-demand balance in three different types of markets: labor, commodities, and foreign exchange; macroeconomic equilibrium between investment and savings.

6. Dynamics: sectoral allocation of investment is assumed to adjust over time to equate rental rates; all other exogenous variables are updated either by exogenous trends or policy choices.

factor accumulation. The intertemporal equations provide all exogenous variables needed for the next period by the CGE model, which is then solved for a new static equilibrium. The model is thus solved forward in a dynamically recursive fashion.

On the supply side, the model distinguishes different economic sectors which produce their output using labor of various skill categories, capital, forest and non-forest land, and intermediate inputs from domestic and imported sources.[3] All sectors except forestry are assumed to operate at constant returns to scale and choose their input quantities so as to minimize production costs for a given level of output at given input and output prices.

The production relationships in the forestry sector are derived from solving on intertemporal optimization problem. It is assumed that foresters maximize their discounted present value of net returns to forest land. Moreover, the model assumes that forestry uses a fixed bundle of non-land inputs per hectare per harvest and so allows for economies of scale in forestry. The resulting set of output supply and input demand equations enables us to examine the conventional forestry policy instruments like resource taxes, secure property rights in the form of long-term concessions, selective logging regimes and the setting-up of national parts.

The labor market is segmented, with three distinct categories of labor: rural labor, urban unskilled labor, and urban skilled labor. Depending on the specific labor market characteristics of the respective economy both a Keynesian version with exogenous real wages and endogenous employment and a neoclassical version with endogenous wages and exogenous employment may be chosen for each skill category. In any case, labor of a given skill category is perfectly mobile between different sectors. Sectoral capital stocks are fixed within periods; they change over time given investable funds and the sectoral allocation of investment. Investment in the sectors is allocated as a function of the relative profit rate of each sector compared to the average profit rate for the economy as a whole. Sectors with a higher-than-average profit rate get a larger share of investable funds.

The total supply of non-forest land is exogenously given and can be used in all agricultural activities. With respect to the supply of forest land, we distinguish two alternative cases. First, the total supply is fixed. This treatment is realistic in cases where land use in forestry

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3 The number of sectors which should be identifiable in the model depends on the structure of forest use and the policies that are relevant for deforestation in the respective country. In Indonesia and Brazil, for example, a regional disaggregation is useful, because regional policies are a major determinant of deforestation and therefore have to be analyzed within the model.

is restricted by concessions and where agricultural production on converted land is mainly due to small-scale farmers who are not able to open up new areas in primary forests. Furthermore, two alternative assumptions about land mobility are possible. If forest land is treated as immobile, this means that the government is able to enforce its previous land use planning. If forest land is treated as mobile between agricultural and forestry uses, one assumes either that the government adjusts its land use planning according to economic criteria or that the concessionaires and farmers have de facto control of land use (Dee, 1991 a). Second, the supply of forest land should be specified as perfectly elastic, if logging is not regulated by concessions or if large agricultural settlements, like in Brazil, are established in the tropical forest. In this case, actual land use is mor likely determined from the demand side than from supply conditions.

Final demands for commodities stem from a single representative consumer, the government, investing industries and foreigners. In the model it is assumed that the representative consumer maximizes a Stone-Geary utility function subject to the budget constraint. Consumer demand resulting from this maximization problem is the linear expenditure system. To minimize the welfare effects of distributional shifts between the single representative household and government, we fix real government expenditure. Government's expenditure shares are also fixed to the initial expenditure shares.

The supply of exports by sector is a function of the ratio of the price in domestic currency of exports to the price of output sold in the domestic market. This treatment partially segments the export and domestic markets. Prices in the two markets are linked but need not be identical. Imports and domestic products are assumed to be imperfect substitutes - an assumption widely used in CGE models of trade. Imports and domestic goods are combined according to a CES trade aggregation function, with consumers demanding the resulting composite goods. The trade substitution elasticity determines the extent to which import shares adjust in response to changes in relative prices. For imports, the world price in dollars is assumed to be constant - the small country assumption - whereas exports may face an elastic demand function.

The equilibrium conditions of the CGE model include a supply-demand balance in three different types of market: labor, commodities, and foreign exchange. A fourth macroeconomic equilibrium condition is the balance between investment and savings - the macro "closure" of the model.

Altogether, the model simulates a market economy where prices for goods, factors, and foreign exchange adjust to equate supply and demand. The model can be used to simulate the effects of changes in government policy or in the external environment by introducing the change and solving for a new supply-demand equilibrium. Since this equilibrium is achieved by adjustments of prices, it is important to specify how each of the components of supply (domestic production and imports) and demand (intermediate demand, consumer demand, government demand, investment demand, and export demand) depend on prices. We begin with the supply of the forestry sector.

2. *Forestry Submodel*

The treatment of forestry presented here follows closely that in Dee [1991 b]. The forestry industry is assumed to maximize its discounted present value of net returns to forest land (harvest revenue net of logging costs), subject to logging technology and the physical growth rates of trees.

We first describe the physical characteristics of the forest. The volume of timber per hectare (TV) depends on the age of the trees (T), a variable that in a mixed age forest is better interpreted as the length of time that trees are left to grow. The timber volume per hectare is given by the following logistic growth relationship (Wilen, 1985):

$$\mathrm{TV(T)} = \frac{MV}{1-[1-MV/TV(0)]e^{-g \cdot T}} \tag{1}$$

where MV is the maximum possible volume of timber per hectare in virgin forests and where g is the maximum intrinsic growth rate of trees. TV(0) is the current average stocking rate across all forests, which is lower than the maximum stocking rate in virgin forests. Along the logistic growth curve holds

$$\frac{\partial TV}{\partial T} = g \cdot \mathrm{TV}\,[1-TV/MV]. \tag{2}$$

The closer the average stocking rate is to the maximum stocking rate, the lower is the additional timber volume that can be gained from delaying harvest and the lower is the intrinsic growth rate of trees.

If the government introduces a selective logging regime, only trees of a minimum age (T^*) can be harvested. This minimum age is a policy variable which can be changed by the government to reach some set-aside target. Under this constraint the volume of timber left standing immediately after the harvest is given by:

$$TV^*(T^*) = \frac{MV}{1-[1-MV/TV(0)]e^{-gT^*}} \tag{3}$$

From equations (1) and (3) the volume of timber cut per hectare per harvest is derived as ($TV - TV^*$) and the time between harvests, the so-called rotation period, is given by ($T - T^*$).

Logging technology is described by a Leontief function which combines land and a non-land input bundle at the top of a multi-level production function.[4] It is assumed that harvesting uses a fixed bundle of non-land inputs per hectare per rotation (XR), the price of which is P_F^i Harvest costs per hectare per rotation are given by

$$RC = P_I^i \cdot XR. \tag{4}$$

Net revenue per hectare per rotation RR is given by

$$RR = \left[P_F^x \cdot \left(TV - TV^*\right) - P_F^i \cdot XR\right] / \left(1 + t_{Fb}^B\right) \tag{5}$$

where P_F^x denotes the producer price in the forestry sector and where t_{Fb}^B is the factor tax rate on forest land, which is another policy vaiable that may be changed by the government to decrease degradation.

4 Substitution possibilities between labor and capital and between imported and domestically produced intermediates are allowed at lower levels of the production tree. See rest of the model in the following subsections.

The discounted present value of net revenues from current and future harvests is calculated, using the discount rate r, as follows

$$PV_F\ (\mathrm{T}) = \frac{RR \cdot e^{-r(T-T^*)}}{1-e^{-r(T-T)^*}} \tag{6}$$

where PV_F denotes the discounted present value of returns per hectare for the forestry industry. The discount rate is another policy variable because it mirrors the security of property rights. Applying a lower discount rate means that concessionaires have more secure tenure (e.g. longer leases). Foresters choose the optimal harvest age T to maximize (6) subject to the above constraints describing harvesting technology (5) and the physical growth of trees [(1) and (3)]. The first order condition is given by

$$\frac{\partial RR}{\partial T} = \frac{\partial RR}{\partial TV} \cdot \frac{\partial TV}{\partial T} = \frac{r \cdot RR}{1-e^{-r(T-T^*)}} \tag{7}$$

where $\frac{\partial RR}{\partial TV} = P_F^x / \left(1+t_{Fb}^B\right)$ from (5)

and $\frac{\partial TV}{\partial T} = \mathrm{g} \cdot \mathrm{TV}\left[1-TV(0)/MV\right]$ from (2)

Equation (7) can be rewritten as

$$\frac{\partial RR / \partial T}{RR} = r\left[1-e^{-r(T-T^*)}\right]^{-1} \tag{8}$$

Equation (8) makes it clear how the first order condition can be interpreted as indicating that trees should be left to grow so long as the rate of growth of net revenues exceeds the discount rate (r) with a correction term which takes into account that when trees are left to grow, this delays not just the current, but all future harvests.

The first order condition implicitly determines the optimal harvest per hectare per rotation. This needs to be translated into annual output for the entire forest. Assuming that the harvest per rotation is equally distributed over the years of the rotation period, annual timber output from the forest is

$$X_F = (TV - TV^*) \cdot B_F / (T - T^*) \tag{9}$$

where X_F and B_F denote the annual output and the quantity of land used by the forestry industry. Similarly, annual non-land input requirements are given by

$$I_F = XR \cdot B_F / (T - T^*) \tag{10}$$

The forestry sector is assumed to choose the composition of its annual non-land input requirement to minimize costs in the same way that other sectors choose their total input requirements. Since the non-land input bundle is fixed per rotation, the forestry sector faces a form of increasing returns to scale.

The annual returns per hectare of land used in forestry, P_{Fb}, are determined by a so-called pure profit condition

$$P_F^s \cdot X_F = P_{Fb} \cdot (1 + t_{Fb}^B) \cdot B_F + P_F^i \cdot I_F. \tag{11}$$

Substituting (9) and (10) into (11) and rearranging leads to

$$P_{Fb} = RR / \left(T - T^*\right). \tag{12}$$

Equation (12) shows that the annual after-tax return to land in forestry, P_{Fb}, is equal to RR [equation (5)], the net revenue per hectare per rotation, divided by the length of the rotation period. Thus the zero pure profit condition simply specifies the obvious relationship between net revenue per hectare per rotation and annual returns per hectare of forest land.

The full model allows for the mobility of forest land between forestry and agricultural activities. Mobility is assumed to take place via the purchase and sale of land. Forest land is reallocated between industries until the discounted present value of after-tax returns to forest land are equalized on a per hectare basis. In forestry, the discounted present value of land rentals is given by equation (6). The capitalized value of after-tax returns to forest land in other sectors i is defined as

$$PV_i = \frac{P_{ib}}{r} \qquad i \neq F. \tag{13}$$

Provision is made for arbitrage via the following equation

$$PV_i = \gamma_{ib} \cdot PV. \tag{14}$$

The stock value of forest land in each industry equals the economy-wide stock value PV, with an industry-specific shift parameter γ_{ib} that indicates differences in rentals as observed in the particular country and that can be used to model distortions in the land market.[5]

3. Rest of the Model

a. Price System

Table 2 presents the equations defining prices in the model. On the import side, the model incorporates the small country assumption: world prices in foreign currency ($\overline{P}^{\$m}$) are exogenous and the domestic price of imports is equal to the world price times the exchange rate (R; domestic currency/foreign currency) times one plus the ad valorem tariff levied on the cif import price. We interpret t_i^m to include the tariff equivalent of other forms of protection in addition to tariffs. Thus it represents the extent to which the domestic price of import good i is raised by protection granted to the corresponding domestically produced commodity. On the export side, for some sectors, a downward sloping world demand curve is assumed: while the country may be unable to affect the world market price with its exports, the country may register a declining market share as, say, its domestic price rises. For other sectors, the small-country assumption is retained, so that world prices are exogenous. On the RHS of equation (16) we have the value (in domestic currency) of exporting a unit of commodity i to the rest of the world - that is, including any export subsidies - and on the LHS we have the cost of doing so, that is, the domestic price.

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5 This shift parameter is also used to modify the mobility assumption for land. The major implication is that with the forestry's demand for land fixed, something else must be permitted to adjust so that the zero pure profit condition holds. The easiest approach is to allow the shift parameter to adjust, which in economic terms corresponds to allowing land rentals to differ in all sectors, with no exogenous pattern imposed. To achieve this result in the computer version of the model, the shift parameter is declared as a variable, rather than as a parameter, which by definition remains fixed. The shift parameter then can vary freely so that the zero pure profit condition holds.

Table 2 - Price Equations

Identifier	Equation	Description
(15)	$P_i^m = \overline{P}_i^{\$m} \cdot (1 + t_i^m) \cdot R$	Domestic price of imports
(16)	$P_i^e = P_i^{\$e} \cdot (1 + t_i^e) \cdot R$	Domestic price of exports
(17)	$P_i^q = \dfrac{P_i^d \cdot D_i + P_i^m \cdot M_i}{Q_i}$	Price of the composite good
(18)	$P_i^x = \dfrac{P_i^d \cdot D_i + P_i^e \cdot E_i}{X_i}$	Output price
(19)	$P_i^v = P_i^x \cdot (1 - t_i^x) - \sum_j P_j^q \cdot a_{ji}$	Value added or net price
(20)	$P_i^k = \sum_j P_j^q \cdot b_{ji}$	Price of a unit of capital
(21)	$P = GDP / RGDP$	GDP deflator

Equations (17) and (18) describe the consumer prices for the composite commodity (Q) and the producer prices for output (X). Q represents a CES aggregation of sectoral imports (M) and that part of domestically produced goods (X) which is supplied to the domestic market (D). X is the sectoral output, which is a CET aggregation of goods supplied to the export market (E) and goods sold on the domestic market (D). Equation (19) 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 the sectoral value added at factor cost, which is distributed to the owners factors.

Equation (20) gives the price (P^k) of a unit of capital installed in sector i. This price is sectorally differentiated because the composition of the capital stock is different across sectors. The sectoral composition of capital goods by sector of origin is determined by the capital coefficients, b_{ij}. Since the b_{ij}'s sum to unity, P^k for each sector is simply the weighted average of the cost of capital goods required to create a unit of capital in each investing sector. By assumption, capital goods are not installed during the period, so that investment represents just another demand category with no effect on supply in the static model. Hence, the heterogeneity of capital is of limited importance within periods, since its effect will emerge through its impact on the sectoral structure of investment final demand. Over time, the heterogeneity assumption is very important and affects the properties of different growth paths.

Finally, equation (21) defines an aggregate price index (P), which is defined as the GDP deflator (nominal GDP divided by real GDP). 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 CGE model can determine relative prices only. The GDP deflator represents a convenient choice for the numeraire in an applied model since it is readily available from national accounts data.

b. Production Technology

Following Condon et al. (1987) we describe the production technology available to each industry in two parts:

(i) the relationship between the industry's inputs and its activity level and
(ii) the relationship between its activity level and commodity outputs.

On the input side we assume that industry production functions exhibit constant returns to scale and are of a three level form (cf. Table 3). At the first level we have the Leontief assumption. That is, there is no substitution between intermediates or between them and an aggregate of the primary factors (aggregate labor, aggregate land, and fixed capital). Intermediate goods are required according to fixed coefficients and so can be treated separately. At the second level we have CES functions (see Armington, 1969) describing substitution possibilities in domestic production between domestically produced and imported goods of the same commodity category. At this level we also have either Cobb-Douglas (CD) or CES functions (see Sato, 1967) describing substitution possibilities between the three groups of primary factors: aggregate labor, aggregate land, and fixed capital.[6] These factors are assumed here to be country specific. At the third level we have either CD or CES functions describing substitution prospects between different labor occupations comprising the aggregate labor category and between different soils (forest and non-forest land) comprising the aggregate land category.[7]

On the output side we allow industries to produce either for the domestic or for the foreign market where the aggregation of domestic sales and exports is described by CET functions (see Powell and Gruen, 1968). This allows us to capture the idea of imperfect transformation between commodities that constitute a sector's output according to changes in relative prices of these commodities in producing the industry's output.[8]

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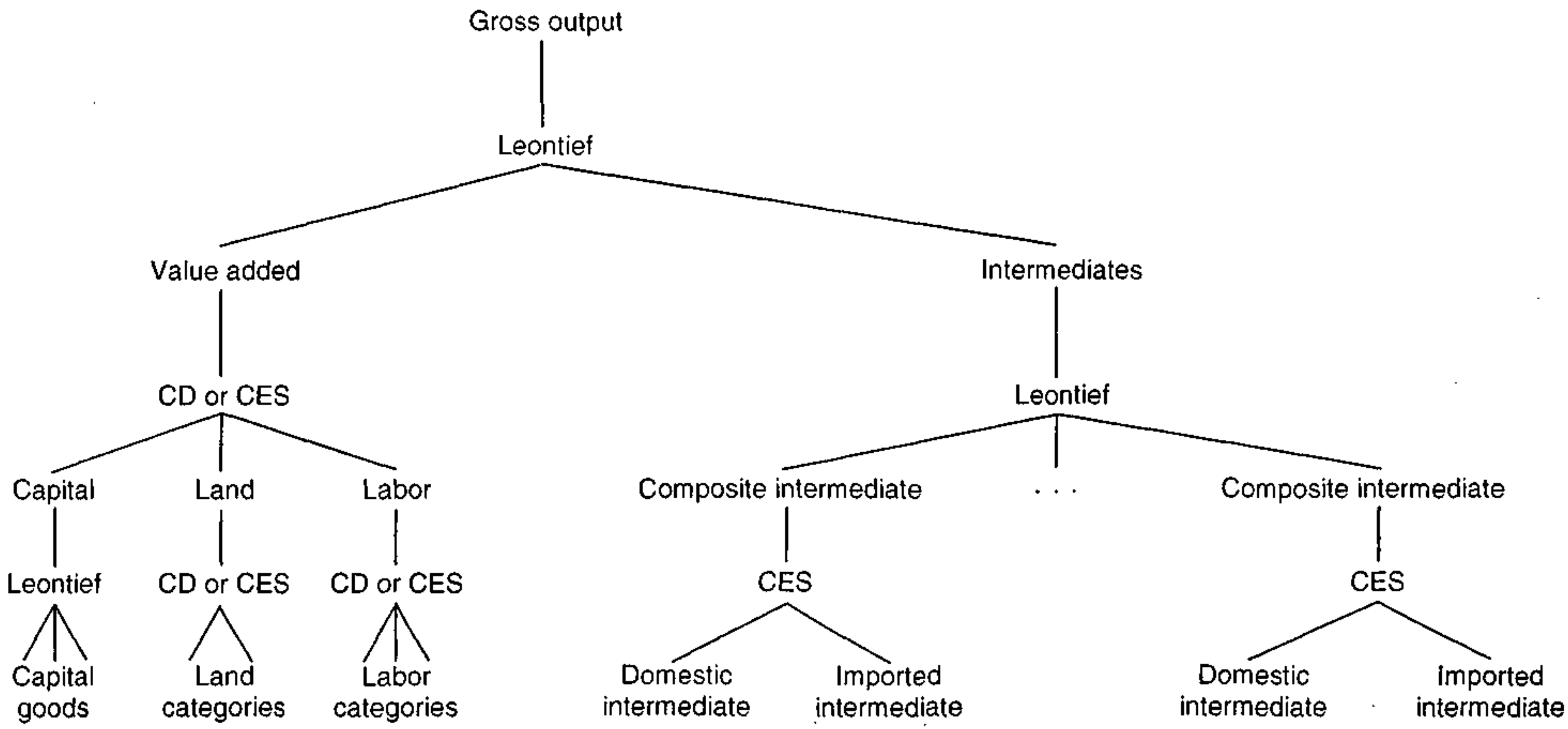
6 We assume the same substitution possibility for all three possible factor combinations.

7 This three level specification of production technology is that used in most CGE systems. While it represents a reasonable tradeoff between the desire to provide a comprehensive treatment of input substitution on the one hand and the availability of estimates of the relevant substitution elasticities on the other, it might well prove restrictive. Production technologies which allow for a greater range of substitution prospects could easily be included in instances where the available microeconomic evidence suggested they are warranted. In particular, the Leontief restriction between intermediate inputs and primary factors could easily be relaxed in specific industries for which contradictory evidence of substitution prospects is available. In specifying an operationally "optimal" production theory it is the knowledge of substitution possibilities at the industry level, rather than theory, which is the limiting factor.

8 For example, export supply may exhibit an excessively strong response to changes in world market prices in the traditional model. As the world market price rises, producers are induced to increase supply and domestic consumers to reduce demand. The net result is a dramatic increase in sectoral exports (the difference between supply and domestic demand). In reality, however, exports may not rise this fast, for the domestically consumed and exported commodities in the same sector may be quite different.

Table 3 - Substitution Possibilities in Production and Input Demand



c. Input Demand and Commodity Supply

Demand functions for the various types of inputs into current production are derived under the assumption that producers minimize their costs of producing a given output level subject to the constraints imposed by the nested production functions outlined above. The various components of the production system and the input demand functions resulting from the solution of the cost minimizing problem are given in equations (22) to (30) in Table 4.

Because intermediates are required in fixed proportions, the CES production functions [equations (22) - (24)] and the CD production functions [equations (22')] can be specified solely as functions of primary factors. Intermediate input demand is given by the Leontief relationship in equation (25), while the composition of imports and domestically produced substitutes resulting from minimizing secondary input costs subject to equation (26) is given in equation (27). In equations (26) and (27) σ_i^Q is the CES substitution elasticity for imported and domestically produced commodities used in domestic production and final demand.[9] If there are no changes in the relative prices of good i from the two sources of supply then a one per cent increase in production leads to a one per cent increase in M_i and D_i. If, however, the prices of domestically produced goods increase relative to imported goods, then producers (and consumers) will substitute away from domestically produced goods in favour of imports. The strength of this substitution effect will depend on the value of the parameter σ_i^Q. If σ_i^Q is very high, the responsiveness of M_i / D_i will be so great that P_i^d / P_i^m will never change much from its base value and we approximate the case of an "extreme small country" which cannot influence its domestic prices by domestic demand decisions and where $P_i^m = P_i^d$. If, on the other hand, σ_i^Q is very low, very large changes in P_i^m / P_i^d may take place. In the extreme case where $\sigma_i^Q = 0$, M_i / D_i would be fixed and we would be in the fixed-coefficients, two-gap model, where relative price changes cannot directly affect demand for imports.

Equations (28) to (30) show the demand for primary factors following from the optimization condition (dropping sectoral subscripts):

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9 We assume that substitution elasticities between imports and domestically produced goods of the same category are the same in all domestic uses. Consequently, the (endogenous) ratio of imports to domestic goods is also the same in all uses.

Table 4 - Input Demand and Commodity Supply

Identifier	Equation	Description
(22)	$X_i = a_i^x \left[\Sigma_f \, \delta_{if}^x \cdot F_{if}^{(\sigma_i^x - 1)/\sigma_i^x} \right]^{\sigma_i^x/(\sigma_i^x - 1)} \quad f = L, B, \overline{K}$	Domestic non-forestry output (CES)
(22')	$X_i = a_i^x \prod_f F_{if}^{\alpha_{if}}$	Domestic non-forestry output (CD)
(23)	$L_i = a_i^L \left[\Sigma_\ell \, \delta_{i\ell}^L \cdot L_{i\ell}^{(\sigma_i^L - 1)/\sigma_i^L} \right]^{\sigma_i^L/(\sigma_i^L - 1)}$	Aggregate labor (CES)
(24)	$B_i = a_i^B \left[\Sigma_b \delta_{ib}^B \cdot B_{ib}^{(\sigma_i^B - 1)/\sigma_i^B} \right]^{\sigma_i^B/(\sigma_i^B - 1)}$	Aggregate land (CES)
(25)	$V_i = \Sigma_j a_{ij} X_j$	Intermediate demand
(26)	$Q_i = a_i^Q \left[\delta_i^Q \cdot M_i^{(\sigma_i^Q - 1)/\sigma_i^Q} + \left(1 - \delta_i^Q\right) \cdot D^{(\sigma_i^Q - 1)/\sigma_i^Q} \right]^{\sigma_i^Q/(\sigma_i^Q - 1)}$	Import aggregation
(27)	$M_i / D_i = \left[\frac{P_i^d \cdot \delta_i^Q}{P_i^m \left(1 - \delta_i^Q\right)} \right]^{\sigma_i^Q}$	Import demand
(28)	$F_{if} = X_i \left[\frac{P_i^v \cdot \delta_{if}^x}{P_{if}} \right]^{\sigma_i^x}$	Primary factor demand (CES)
(28')	$F_{if} = \alpha_{if} \cdot \frac{P_i^v \cdot X_i}{\gamma_{if} \cdot P_f \cdot \left(1 + t_{if}\right)}$	Primary factor demand (CD)

to be continued ...

Table 4 continued ...

Identifier	Equation	Description
(29)	$L_{i\ell} = L_i \left[\frac{P_i^L \cdot \delta_{i\ell}^L}{\gamma_{i\ell} \cdot P_\ell (1 + t_{i\ell}^L)} \right]^{\sigma_i^L}$	Demand for labor categories (CES)
(30)	$B_{i\ell} = B_i \left[\frac{P_i^B \cdot \delta_{ib}^B}{\gamma_{io} \cdot P_b (1 + t_{ib}^B)} \right]^{\sigma_i^B}$	Demand for land categories (CES)
(31)	$X_i = a_i^T \left[\delta_i^T \cdot E_i^{(1+\rho)/\rho_i} + (1 - \delta_i^T) \cdot D_i^{(1+\rho_i)/\rho_i} \right]^{\rho_i/(1+\rho_i)}$	Domestic sales-export transformation
(32)	$E_i = D_i \left[\frac{P_i^e (1 - \delta_i^T)}{P_i^d \cdot \delta_i^T} \right]^{\rho_i}$	Export supply

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

where F refers to primary factors and P^v is the value-added price defined in equation (19).[10]

Equations (28) to (30) have a similar form to (27). That is, the left hand side variable is explained by a scale factor and a substitution factor. In (28) σ_i^x is the substitutuion elasticity for aggregates of factors (labor, capital, land) in industry i and δ_{if}^x is the distribution parameter. Equation (28) implies that increases in the cost of any factor relative to the value-added price - that is, to a weighted average of the prices of the three factor aggregates - leads to substitution away from that factor.

Similarly, equations (29) and (30) indicate that if there is no change in the relative prices of the different types of labor or the different types of land then the occupation composition of industry i's work force or industry i's land use pattern will remain unchanged. However, if the price of one type of labor or land increases relative to a weighted average of all the occupational wage rates or land rental rates then industry i's use of this type of labor or land will decrease relative to the use of other types.

Such price increases of factors may be the result of an economy-wide price increase ($\Delta P_f > 0$), of higher factor taxes ($\Delta t_{if} > 0$) or of higher factor prices in individual sectors ($\Delta \gamma_{if} > 0$).[11]

In the case of Cobb-Douglas production technology with unitary elasticities of substitution between all categories of primary factors [equation (22')] the factor demand equations collapse to (28').

Commodity supply equations are derived by assuming that at any given activity level producers choose their composition of export goods and domestic goods to maximize their revenues subject to the transformation function given in equation (31). The solution to this revenue maximizing problem yields the export supply equation (32).

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10 The same approach has been used to derive demand functions for labor and the capital rental in the forestry sector. There, P^V is the price index of the bundle of non-land primary factors and F refers to labor and capital only.

11 The model allows for price differentials across sectors (γ_{if}) which may reflect either different marginal productivities of the same factor or distortions in factor markets.

Equation (32) relates industry i's supply of exports to domestic sales and to the domestic price ratio of export and domestic sales. If there are no relative commodity price changes then industry i is indifferent between producing export goods or local goods. If, however, the domestic price of exports increases relative to the price of domestic goods then industry i transforms the commodity composition of its output in favor of export commodities. The strength of this transformation effect is governed by the transformation elasticity ρ_i. If ρ_i is very high, the responsiveness of E_i / D_i to small changes in P_i^e / P_i^d will be so large that the domestic supply would be reduced dramatically. This would clearly exert upward pressure on the domestic price P_i^d and we approximate the case where $P_i^e = P_i^d$. If on the other hand, ρ_i is very low, very large changes in P_i^e / P_i^d may take place without any significant effect on the composition of sectoral supply.

d. Flow of Funds

Table 5 presents the equations which map the flow of income from production to institutions and ultimately to households. Many of the income and expenditure flows they represent are specific to the structure of a particular economy.

Equation (33) defines net factor incomes which in turn are distributed to households in equation (34). Equations (35) - (38) determine government revenues from factor taxes (T^f), import tariffs (T^m), indirect taxes (T^x), and household income tax (T^H), equations (39) sums up sectoral export subsidies (T^e), while total government revenue (Y^G) is obtained as their sum in equation (40). The components of savings include financial depreciation (DEP) in equation (41), households savings (S^H) from fixed savings propensities (s^H) in equation (42), and government savings (S^G) in equation (43), obtained as the difference between government revenue and consumption. Total savings (S) in equation (44) includes these three elements plus foreign savings in domestic currency $S^F \cdot R$.

Note that these income equations also embody the three major macro balances: savings-investment balance, the government deficit, and the balance of payments. Enterprises and households save fixed proportions (Ω and s^H) of their incomes, government saving is the budget surplus or deficit, and foreign savings represent the capital inflow required to balance international payments, i.e. net foreign savings. Since the model satisfies Walras' Law, the three macro balances must satisfy the identity:

private savings + government savings + foreign savings = investment.

Table 5 - Income Equations

Identifier	Equation	Description
(33)	$Y_f^F = \sum_i P_f \cdot F_{if} \cdot \gamma_{if}$	Net factor income
(34)	$Y^H = \sum_f Y_f^F - DEP$	Household income
(35)	$T^m = \sum_i \overline{P}_i^{\$m} \cdot M_i \cdot t_i^m \cdot R$	Tariff revenues
(36)	$T^f = \sum_i P_f \cdot F_{if} \cdot \gamma_{if} \cdot t_{if}$	Factor tax revenues
(37)	$T^x = \sum_i P_i^x \cdot X_i \cdot t_i^x$	Indirect tax revenues
(38)	$T^H = Y^H \cdot t^H$	Household income tax revenues
(39)	$T^e = \sum_i P_i^{\$e} \cdot E_i \cdot t_i^e \cdot R$	Export subsidy expenditures
(40)	$Y^G = T^m + T^f + T^x - T^e + T^H$	Government revenues
(41)	$DEP = \sum_i \Omega_i \cdot P_i^k \cdot F_{if} \quad f = capital$	Depreciation
(42)	$S^H = Y^H(1 - t^H) \cdot s^H$	Household savings
(43)	$S^G = Y^G - \sum_i P_i^q \cdot \overline{C}^G$	Government savings
(44)	$S = S^H + S^G + DEP + S^F \cdot R$	Total savings

e. Final Commodity Demand

Table 6 provides equations which complete the circular flow in the economy, determining the demand for goods by the various actors. Private consumption (C_i^H) is obtained in equation (45) by applying the Stone-Geary linear expenditure system (LES), where τ_i are the commited expenditures or "subsistence minima" in physical terms, and β_i are the marginal budget shares that determine the allocation of supernumerary income (i.e. expenditure above that required for purchasing the subsistence minima).[12] In equation (46), government demand (C_i^G) for final goods is defined using fixed shares of aggregate real spending on goods and services. Inventory demand ($Z2_i$), or change in stocks, is determined in equation (47) using fixed shares of sectoral production. Aggregate nominal fixed investment (FI) is calculated in equation (48) as total investment minus inventory accumulation. Aggregate fixed investment is converted into real sectoral investment by sector of destination (DK_i) in equation (49) using fixed nominal shares $\left(k_i\right)$, which sum to one over all sectors. These investment allocation shares are updated over time according to deviations of the sectoral rental rates from the average rental rate (see below). Equation (50) translates investment by sector of destination into demand for capital goods by sector of origin $\left(Z_i\right)$, using fixed coefficients for the sectoral composition of the capital stock (b_{ij}). Equation (51) gives the world export demand function for sectors in which the economy is assumed to have some market power and therefore faces a downward sloping demand curve. Equation (52) and (53) define nominal and real GDP, which are used to calculate the GDP deflator specified as 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).

[12] Given average budget shares from national accounts data or household expenditure systems, there are a variety of ways to estimate the parameters of the system depending on the extent and quality of available data. See section III.3 for calibration of the household's demand equations.

Table 6 - Expenditure Equations

Identifier	Equation	Description
(45)	$C_i^H = \tau_i + \frac{\beta_i}{P_i^q}\left[Y^H(1-s^H)(1-t^H) - \sum_j P_j^q \cdot \tau_j\right]$	Private consumption
(46)	$C_i^G = c_i^G \cdot \overline{C}^G$	Government consumption
(47)	$Z2_i = z_i \cdot X_i$	Inventory demand
(48)	$FI = I - \sum_i P_i^q \cdot Z2_i$	Aggregate nominal fixed investment
(49)	$P_i^k \cdot DK_i = k_i \cdot FI$	Nominal fixed investment by sector of destination
(50)	$Z_i = \sum_j b_{ij} \cdot DK_j$	Demand for capital goods by sector of origin
(51)	$E_i = \overline{E}_i \left[\frac{P_i^{\$e}}{\overline{P}_i^{\$e}}\right]^{-\eta_i}$	Export demand
(52)	$GDP = \sum_i P_i^v \cdot X_i + T^x + T^m - T^e$	Nominal GDP
(53)	$RGDP = \sum_i\left(C_i^H + C_i^G + Z_i + Z2_i + E_i - \overline{P}_i^{\$m} \cdot M_i \cdot R\right)$	Real GDP

f. Market Clearing and Macro-closure

Table 7 contains equations defining the system constraints that the model economy must satisfy. Equation (54) 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 domestic markets (D). However, from equation (27) it is evident that the ratio of imports to domestic sales is the same for all categories of domestic final demand. 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 (54) by the ration D_i / Q_i. Since, if equation (54) holds, so will this new equation, no separate equation is required.[13]

The equilibrating variables for equation (54) are sectoral prices. There are nine prices in the model which have sectoral subscripts: $\overline{P}^{\$m}$, $P^{\$e}$, P^e, P^m, P^q, P^x, P^v, P^d, and P^k. The world prices ($\overline{P}^{\$m}$ and $P^{\$e}$) are treated separately. Of the remaining seven, six appear on the LHS of price equations in Table 2, leaving P^d as the variable "free" to adjust.

Equation (55) defines equilibrium in factor markets. The supplies of primary factors ($\overline{F}^s$) are fixed exogenously.[14] Market clearing requires that total factor demand equal supply, and the equilibrating variables are the average factor prices (P_f). In the model specified here, all labor categories are intersectorally mobile, agricultural land is mobile across agricultural activities, and forest land is mobile across all forest-land using activities, while sectoral capital stocks are assumed to be fix within each period. For mobile factors, factor demands in all sectors as well as capital and labor demand in forestry are determined through equations (29) and (30) or (28') and market clearing is achieved via changing factor prices (P_f) together with exogenous sector-specific parameters (γ_{if}). Fixing capital stocks means that the factor demand of equation (28) or (28') are fixed, so that aggregate supply and demand are automatically equal, and the market-clearing condition for capital in equation (55) is redundant and can be dropped. Without factor mobility, however, sector 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 γ_{if} parameters. Thus, with fixed capital stock (or fixed land in forestry) the γ parameters become endogenous.

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13 The same reasoning can be used to justify why there is no separate market-clearing condition for domestic output (X), since this involves adding exports to both sides of this adjusted market-clearing condition.

14 See the following section for alternative general equilibrium conditions.

The remaining two equations describe macroeconomic equilibrium conditions for the balance of payments and savings-investment balance. Satisfying each of these requires to select variables that will adjust freely to achieve equilibrium and constrain other variables by fixing them exogenously. In equation (56) the balance of payments is represented in the simplest conceivable from: foreign savings 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^e and P^m) relative to domestic 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.

Table 7 - Market Clearing Conditions and Macroeconomic Closure

Identifier	Equation	Description
(54)	$Q_i = V_i + C_i^H + C_i^G + Z_i + Z2_i$	Equilibrium in product markets
(55)	$\sum_i F_{if} = \overline{F}_f^S$	Equilibrium in factor markets
(56)	$\overline{P}_i^{\$m} \cdot M_i = P_i^{\$e} \cdot E_i + S^F$	Balance of payments
(57)	S = I	Savings-investment balance

The final macro-closure condition in equation (57) requires that the 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, private savings are determined by fixed saving rates, and foreign savings are fixed exogenously. This model specification corresponds to a "saving driven" model, in which aggregate investment is the endogenous sum of the separate savings components. This is often called "neoclassical" closure in CGE literature.

4. Alternative Model Closures

The endogenous and exogenous variables can be chosen in many different ways, thus allowing the model to be applied to a wide range of economic policy issues. Table 8 gives one possible model closure designed to reflect a short run macroeconomic environment. In discussing the list of exogenous variables we also draw attention to some alternative selections of exogenous variables.

The first variables in Table 8 are the current capital stocks. Their exogenous treatment specifies a short run environment. Implicit is the assumption that changes in industry capital stocks associated with the exogenous shock under study can be ignored. For long run simulations (in a comparative static model) they could be replaced on the exogenous list by the industry rates of return variables P_{iK}. The underlying assumption in such a simulation would be that, over the long term, industry capital stocks adjust to levels at which they earn their exogenously specified rates of return. Alternatively, the within-period comparative static model can be extended by dynamic equations capturing cumulative processes that drive the CGE model forward in time (see section 5).

The second group of variables are the B_{ib}, the country level of land use. With the B_{il}'s exogenous, the model determines changes in the rental prices of forest and non-forest land in the agricultural sectors and forestry P_{ib}. Alternatively it can be assumed that total land supplies are fixed but can be used in different activities. In this case land use pattern would adjust to equate land rental prices across sectors.

Next we have the wage distribution parameter γ_{il} and the wage rates P_l. Their inclusion on the exogenous list indicates that wages, rather than employment levels of labor are

Table 8 - One Possible Selection of Exogenous Variables

Variable	Subscript Range	Number	Description
K_i	i = 1,..., n	n	Current capital stocking sector i
B_{ib}	i = 1,..., n b = 1	n	Use of nonforest land in sector i
γ_{il}	i = 1,..., n c = 1, 2, 3	3 n	Shift factor for the price of labor categories in sector i
P_l	c = 1, 2 , 3	3	Price of labor categories
$P_i^{\$m}$	i = 1,..., n	n	Cif import price of commodity i
t_i^m	i = 1,..., n	n	Ad valorem rate of protection on imports of good i
t_i^x	i = 1,..., n	n	Indirect tax on domestic consumption of good i
t_i^e	i = 1,..., n	n	Ad valorem export subsidy rate on good i
T^*		1	Minimum harvest age
B_{ib}	i = 1,..., m b = 1	m	Employment of forest land in agriculture and forestry
r		1	Discount rate for forestry
t_i^x	i = 1,..., m	m	Indirect tax on domestic consumption of agrigultural and forestry goods
t_{ib}^B	i = 1,..., m	m	Factor tax on forest land
S^F		1	Foreign savings
s^H		1	Household's savings rate

determined exogenously (demand determined labor markets). One alternative, perhaps more applicable for the medium run, would be to fix the economy-wide labor supply and let P_l adjust to clear labor markets at pertaining labor market distortions (γ_{il} = constant). Finally, in the longrun L_l may be constant exogenous, labor market distortions vanish (γ_{il} = 1) and sectoral wages adjust to the endogenous economy-wide wage rates ($P_{il} = P_l$).

The next exogenous variables are the $P_i^{\$m}$, the cif import prices for commodities imported from the rest of the world. By placing these on the exogenous list we are adopting the small country assumption, i. e. prices, in foreign currency, are independent of domestic import demands. We are also allowing for the computation of answers to questions of the form: what will be the effects of projected changes in the rest of the world supply prices of imports for the domestic economy?

The next group of variables are the ad valorem rates of protection on imports from the rest of the world. With these variables exogenous the model can be used to tackle questions of the form: what would be the macro economic and sectoral effects of changes in protection levied against imports from the rest of the world? Would a more liberalised agricultural trade reduce deforestation?

Next on the list are the t_i^x, representing indirect taxes on domestic consumption. By assumption these indirect taxes are paid in production, but are borne by domestic consumers. Introducing or increasing a tax on forest output would put a value on the unpriced ecological benefits that harvesting destroys.

The next variables are the ad valorem export subsidies t_i^e. Their inclusion on the exogenous list indicates that the corresponding commodity exports are determined endogenously. We see from equation (16) that with export subsidies exogenous, movements in selling prices in the rest of the world, $P_i^{\$e}$, are set by movements in domestic prices, P_i^e, after taking into account exchange rate changes. Of course, how much is sold at these prices depends, in addition, on local prices for competing products in the rest of the world, $\overline{P}_i^{\$e}$ [see equation (51)] and the ease of transformation between domestic sales and exports [see equation (32)]

We consider the next three sets of variables, T^*, B_{ib}, r, t_i^x and t_{ib}^B together, because these are some of the conventional forestry policy instruments that are used in tropical countries or have been suggested in the literature, in order to increase the volume of standing timber. The first is an increase in the minimum age of trees that can be harvested (T^*). The intention is to increase the average size of trees standing in the forest, thereby increasing the volume of standing timber (TV^*). The target will be reached so long as there is no strong offsetting incentive to reduce the area of land devoted to forestry. The second instrument is a direct set-aside in the form of a national park. An increase in national parks is modeled as a reduction in total area available for forestry and agricultural conversion (B_{ib}; i = export crops, cash crops, forestry; b = forest land). The third instrument is an increase in the length of forest leases so that concessionaires have a better incentive to view forestry as a long-term business. This can be modeled as a reduction in the discount rate (r) which concessionaires use to calculate their returns from forestry. The point here is that uncertainty over future tenure produced by the current lease arrangements is likely to mean concessionaires apply a higher discount rate than elsewhere. More secure tenure is an instrument that can be used to lower their discount rate. The last two instruments are taxes on forest and agricultural output (t_i^x) and taxes on forest-land input (t_{ib}^B; i = cash crops, food crops, forestry; b = forest land) to put a value on the unpriced ecological benefits that harvesting destroys. This might be called the Pigouvion solution.

The final two exogenous variables close the foreign exchange market and the savings-investment balance. With foreign savings (S^F) set exogenously, the equilibrating variable is the exchange rate. Alternative foreign exchange market closure choices are possible. For example, the exchange rate can be fixed, and foreign savings can adjust. Alternatively, the price index (P) can be fixed exogenously, with both R and S^F determined endogenously. In fact, what the model determines is a staple relationship between the real exchange rate and the balance of trade. As with the balance of payments, there are alternative ways to achieve savings-investment equilibrium in CGE models. As specified in the model equations, aggregate investment is the endogenous sum of the various institutional savings components. This "savings driven" closure is often called "neoclassical" closure in the CGE literature. Various "investment driven" closures are possible in which aggregate investment (I) is fixed and some savings components or parameter (such as s^H or S^F) becomes endogenous. "Keynesian" closures, which incorporate multiplier mechanisms, are possible as well.

5. Dynamics

The dynamic equations capture cumulative processes that drive the CGE model forward in time. These processes reflect three different types of forces: exogenous trends, government policy choices, and past history incorporating solutions of the model for previous periods.

Table 9 summarizes the set of variables to be updated by the dynamic linkage equations in the dynamic model. Investment allocation is the core of the between-period model and together with trend equations and the updating of government policy variables, allows the model to be run forward in time. We shall therefore present the simple investment allocation model used to update sectoral capital stocks in the dynamic model.

In the static model, the structure of investment by sector of destination was treated predetermined. We adjust these proportions as a function of the relative profit rate of each sector compared to the average profit rate for the economy as a whole. Sectors with a higher than average profit rate would get a larger share of investable funds than their share in aggregate profits. The shares are given by

$$k_{it} = shr_{i,t-1} + \mu \cdot shr_{i,t-1} \frac{SR_{i,t-1} - AR_{t-1}}{AR_{t-1}}$$

where shr_i = sectoral share in aggregate profits

SR_i = sectoral profit rate

AR = average profit rate

μ = mobility of investable funds parameter

When the investment mobility parameter μ is zero, there is no intersectoral mobility of investment funds. In essence, all investment is financed by retained profits (ignoring savings from government, households, and abroad). When μ is positive, the sectoral allocation of investment will respond to profit rate differentials and high profit sectors will attract funds from low profit rate sectors. Thus μ measures the intersectoral mobility of investment funds.

Table 9 - Endogenous Variables of the Dynamic Model

- Parameters that remain unchanged
  - Input - output coefficients
  - Capital composition coefficients
- Variables and parameters that are updated by exogenous trends
  - Aggregate labor force
  - Sectoral total factor productivity
  - Variables determined in the rest of the world
  - Private consumption shares
- Variables that are updated by policy choices
  - Tax rates and government consumption shares
  - Overall price index
  - Tariffs and export subsidies
  - Discount rate
  - Minimum age of trees that can be harvested
  - Forest land devoted to national parks
- Variables that are updated by economic behavior
  - Sectoral capital stocks
  - Sectoral investment allocation

III. Numerical Specification: The Cameroon Model

Two steps are involved in the numerical specification of the model for a particular country [Mansur, Whalley, 1984]. First, a benchmark equilibrium data set has to be constructed, which describes in a consistent manner the flow of money and products between all economic agents included in the model. Second, the parameters of the model have to be calibrated in such a way that the model can reproduce the benchmark data.

1. Reference Year, Data Sources, and Disaggregation

In specifying the numerical model for Cameroon, we chose 1979/80[15] as the base year, since the most complete set of data is available for this year. Major information with which to make the model operational are taken from the Cameroonian input-output table for 1979/80 [Government of Cameroon, 1983] which is based on and consistent with the 31-sector national accounts for the same fiscal year. This is supplemented by data from a Cameroonian social accounting matrix [Condon et al., 1987] which allow labor to be disaggregated into different occupations and also provide information on investment by sector of destination. Data on Cameroon's resource base [Djophant, Tchounkoue, 1992] allow gross operating surplus to be split into returns to fixed capital and land. Finally, information on forest stocks and growth rates with which we develop parameters for the forest growth equations stem from FAO (1981) and foreign trade elasticities are taken from Devarajan et al. (1991). Because no information was available on substitution elasticities in production and income elasticities in private consumption we assumed Cobb-Douglas production technologies and Cobb-Douglas utility functions. Under these assumptions the required parameters of the production and the consumption functions can be calculated directly from the benchmark data.

The level of the required sector-wise disaggregation of the model (and the data base) is determined by the distortions and the policies the model user wants to analyze. In an open economy, a distinction must be made according to tradability. In Table 10 we separate construction and public services as pure non-traded sectors (9, 11) from all other sectors (1

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[15] Cameroonian national accounts use a fiscal year starting July 1.

Table 10 - Sector Classification

Model category	Classification of Cameroonian input-output table[a]
1 Food crops[b]	(1) Agricultural crop production; (3) Breeding and hunting; (4) Fishing
2 Cash crops	(2) Agricultural production for industry and exports
3 Forestry	(5) Forestry and logging
4 Wood processing	(14) Processing of wood and wood products
5 Consumer goods	(7) Production of flour and vegetables; (8) Processing of agricultural products; (9) Bakery, pastry, and fancy pastes production; (10) Other food production; (11) Beverages and tobacco; (12) Textile and apparel production; (13) Shoe and leather industry
6 Intermediates	(15) Paper and paper goods production, painting and publishing; (16) Processing of chemicals and chemical products; (17) Rubber and plastic production manufacture; (22) Other manufacturing industries
7 Base materials	(23) Electricity, gas, and water; (18) Production of construction materials; (13) Base metal industries
8 Capital goods	(20) Fabricated metal products, machinery, and equipment manufacture; (21) Fabricated transport equipment manufacture
9 Construction	(24) Construction
10 Private services	(25) Whole sale and retail trade; (26) Restaurant and hotel trades; (27) Transport, storage, and communication industries; (28) Financial institutions; (29) Real estate and business services; (30) Services
11 Public Services[c]	(31) Public administration

[a]The English names of the production sectors come from the National Accounts of Cameroon (1984/1985), which are presented both in French and English. - [b]Including livestock and fishery. - [c]Including producers of private non-profit services to households and domestic services of households.

- 8, 10). Because the focus is on policies to change land-use patterns emphasis is given in traded sectors to agriculture and forestry (1 - 3) and their forward and backward linkages to other production sectors. In agriculture a sectoral distinction is made with respect to differences in trade orientation and effective protection between food crops and cash crops.

2. Construction of a Consistent Data Set

a. An Aggregate SAM for Cameroon

A condensation of much of the data required to operationalize the model is presented in the aggregate social accounting matrix (SAM) of Table 11. As in all SAMs, the Cameroonian SAM has the same number of rows and columns, which represent, respectively, receipts and expenditures of economic agents. As in all accounting, each agent's expenditure equals, after account is taken for savings and dissavings, that agent's total receipts. The latter proposition simply follows from the definition of savings.

Using these identities, SAMs can present the circular flow of national income in a convenient form. Starting with production (or, indeed, at any point in the circle), one can identify the incomes paid to factors of production, trace these to household incomes and then to household consumption expenditures, and from these (and other) expenditures back to the factor incomes. From this basic circular flow there are leakages and additions, which must be subtracted or added. The sum of these must balance in a consistency check known as Walras' Law or the savings-investment identity.

To follow through the circular flow of income in Cameroon as represented in a SAM, it is easiest to begin with the production accounts. They are given as the first two rows and columns in Table 11. The first two rows are essentially the familiar input-output balances, showing the demands under various categories for domestically produced goods and domestically supplied goods. Reading first across the sectors row, we observe that total revenues (1939.5 billion CFA Francs) derive from domestic sales to the commodity account (1586.0) and exports (sales to the rest of the world: 378.6).[16] The sectors column contains all expenditures on inputs into the production process: on intermediate inputs

[16] It is assumed that the domestic price value of exports is higher (lower) than the foreign price value by the amount of the export subsidy (tax). Under the small country assumption, the incidence of export duties is on domestic producers. In the case of price elastic export demand, the incidence is shared by domestic producers and foreign buyers. In any case, world price value and subsidies or taxes sum to exports in producer prices.

Table 11 - Aggregate SAM for Cameroon, 1979/80 (CFA francs billion)

	Production		Factors	Institutions Current			Consolidated capital	Rest of the World	Totals
	Sectors (1)	Commodities (2)	(3)	Enterprises (4)	Households (5)	Government (6)	(7)	(8)	(9)
Sectors (1)		1586.0				-25.1		378.6	1939.5
Commodities (2)	684.9				948.0	135.0	281.1		2048.9
Factors (3)	1177.3								1177.3
Enterprises (4)			594.0						594.0
Households (5)			583.3	462.3					1045.6
Government (6)	77.3	76.6							153.9
Consolidated Capital (7)				131.7	97.6	44.0		7.7	281.1
Rest of the World (8)		386.3							386.3
Totals (9)	1939.5	2048.9	1177.3	594.0	1045.6	153.9	281.1	386.3	

(684.9), on primary factors (1177.3), and on indirect taxes (77.3).[17] The sum of these input expenditures equals gross revenues.

The commodity account represents the domestic commodity market. In the column, it shows purchases of domestic products from domestic production sectors (1586.0) and purchases from the rest of the world (386.3); it also pays import tariffs to the government (76.6).[18] The commodity row shows how the total absorption of commodities is demanded by domestic purchasers, including intermediate inputs (684.9), household consumption (948.0), government consumption (135.0), and investment (281.1).

In the factors account, total value added at factor costs (1177.3) is allocated to the owners of factors: enterprises (594.0) and households (583.3). Out of their income, enterprises retain a part (financial depreciation and retained earnings: 131.7) to buy investment goods, and distribute the rest to the household sector (proprietor income and distributed profits: 462.3).

The household account shows that households divide their income (1045.6) between savings (97.6) and consumption (948.0). Similarly, in the government account, the government receives income from taxes (including tariffs: 76.6, export taxes: 25.1, and indirect taxes: 77.3) and spends it in consumption (135.0) and savings (44.0). The last two rows and columns contain familiar national accounts identities. The capital account reflects the equality between savings (the row, comprised of private savings: 131.7 + 97.6, public savings: 44.0, and foreign savings: 7.7) and investment (the column: 281.1). The rest of the world account represents the equality between foreign exchange expenditures (imports: 386.3) and foreign exchange earnings (exports: 378.6 plus foreign savings: 7.7).

b. Input-Output Table

The description of the basic relations of the Cameroonian economy is based on the 31 sectors input-output table for 1979/1980 which is fully consistent with the national accounts for that fiscal year. For the analysis of deforestation and degradation, there is clearly no point in working at a 31-sector disaggregation. Land use patterns are definitely not determined by interactions between industries at such a fine level, but rather at the agriculture versus forestry versus manufacturing versus services level. We, therefore,

[17] We assume that all indirect taxes are paid in production. However, the incidence of the tax is on consumers because market prices are higher by the amount of the indirect tax rate.

[18] The incidence is on consumers, since market prices are higher by the amount of the tariffs.

aggregated the 31 sectors to 11 sectors according to the sector classification scheme given in Table 11. The final input-output table resulting from this aggregation is presented in Table 12 and is a matrix of total transactions including imports.

Table 13 provides a summary of the most important structural features of the Cameroonian economy. Columns (1) and (2) describe the structure of production and value added across sectors. These reveal a typical composition of output and value added found in developing countries where agriculture and services provide more than 60 per cent of gross domestic production and over 70 per cent of value added. Food crops and private services alone account together for nearly 65 per cent of value added. The importance of intermediate inputs in each sector is indicated by the per-unit value added in column (3). High value-added ratios in food crops and forestry indicate small backward linkages. By contrast, the manufacturing sectors exhibit the lowest value-added rations suggesting high backward linkages.

The next three columns provide information about each sector's trade orientation. Column (4) indicates that eight out of nine tradeables-producing sectors export more than 10 per cent of their output, with cash crops and forestry being the most export-oriented sectors in the economy. On the import side, the typical picture emerges when one considers both the share of import in domestic absorption (which indicates the degree of import "orientation") and the share of imports inputs in total intermediate inputs (which indicates the degree of import "dependence"). Cash crops and the manufacturing sectors are the most import-oriented sectors and all sectors are highly import-dependent. Construction an public services are the only non-trade sectors, yet 45 and 19 per cent of their inputs are imported.

c. Sectoral Distribution of Factor Inputs and Value Added

The construction of the input-output table yields a consistent set of sectorally disaggregated production and income (value added) accounts. The next step is to distribute the sectoral value added shown in Table 12 to the various factors of production included in the model. This requires the determination of rates of return to each category of factors, which necessarily limits the number of factor categories that can be defined in a meaningful way. Data on wage rates as well as rental rates for capital and land are scarce in most developing countries. This is also the case in Cameroon, where values for different labor categories can be obtained from Condon et al. (1987) but values for productive capital and land can be determined only imperfectly.

Table 12 - Input-Output Table for Cameroon, 1979/80 (CFA francs billion, current producer prices)

	Sector	1	2	3	4	5	6	7	8	9	10	11	Total	Private consump-tion	Governmen t consump-tion	Gross fixed capital formation	Increase in stocks	Exports	Imports	Total gross production
1	Food crops	11.54	0.00	0.00	0.00	23.75	0.00	0.00	0.00	0.00s	22.26	0.00	0.00	255.86	4.19	6.71	4.04	4.59	-2.46	330.49
2	Cash crops	0.00	1.89	0.00	0.00	3.07	1.70	0.00	0.00	0.00	0.00	0.00	0.00	4.22	0.00	0.00	3.51	100.00	-8.04	106.34
3	Forestry	0.00	0.00	0.00	6.01	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.92	22.32	0.00	29.49
4	Wood processing	0.10	0.31	0.15	0.32	0.37	0.18	0.01	0.12	0.09s	1.43	2.27	0.00	9.29	0.00	0.00	0.00	5.46	-1.34	18.78
5	Consumer goods	1.40	0.76	0.00	0.06s	10.67	2.32	0.00	0.00	0.00	1.19	2.78	0.00	186.69	0.00	0.00	10.29	29.32	-55.02	190.45
6	Intermediates	2.98	16.25	0.47	1.59	13.42	61.48	6.37	0.04	25.99	4.60	11.45	0.00	157.06	1.76	0.00	3.49	95.87	-137.23	265.59
7	Base materials	0.01	0.03	0.01	0.15	16.15	14.44	9.28	1.19	31.92	0.11	0.00	0.00	0.00	0.00	0.00	0.00	10.50	-49.62	34.17
8	Capital goods	0.19	1.30	0.73	0.63	2.39	13.68	0.72	0.53	4.58	2.53	0.00	0.00	0.00	0.00	113.35	0.53	3.84	-134.72	10.30
9	Construction	2.00	0.14	0.09	0.00	11.19	13.38	0.06	0.00	2.41	2.33	0.60	0.00	0.00	3.79	138.13	0.00	0.00	0.00	174.11
10	Private services	1.67	40.18	7.85	1.63	40.77	59.48	4.04	s1.02	23.87	87.28	38.37	0.00	298.77	3.65	0.00	0.00	81.63	-74.44	615.78
11	Public services	0.09	0.37	0.09	0.30	1.09	2.13	0.16	0.01	0.75	1.33	0.00	0.00	36.01	121.62	0.00	0.00	0.00	0.00	163.96
	Total	19.97	61.24	9.40	10.68	123.12	168.79	20.64	2.92	89.62	123.06	55.47	0.00	947.90	135.02	258.20	22.79	353.52	-462.87	1939.45
	Value added	309.85	45.11	18.41	7.14	53.24	90.42	13.05	7.08	78.58	445.91	108.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Indirect tax	0.66	0.00	1.68	0.96	14.09	6.37	0.48	0.30	5.92	46.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Total gross production	330.49	106.34	29.49	18.78	190.45	265.59	34.17	10.30	174.11	615.78	163.96	0.00	947.90	135.02	258.20	22.79	353.52	-462.87	1939.45

Table 13 - Sectoral Characteristics of the Cameroonian Economy, 1979/80

Sector	Composition of		Per unit value added	Exports/Gross output	Imports/ Absorption	Imported/Total intermediates
	output (1)	value added (2)	(3)	(4)	(5)	(6)
Food crops	17.0	24.7	0.94	1.4	0.8	10.9
Cash crops	5.5	3.6	0.42	94.0	55.9	24.0
Forestry	1.5	1.6	0.62	75.7	-	20.1
Wood processing	1.0	0.7	0.38	29.1	9.1	15.5
Consumer goods	9.8	5.4	0.28	15.4	25.5	23.4
Intermediates	13.7	7.7	0.34	36.1	44.7	35.0
Base materials	1.8	1.1	0.38	30.7	67.7	50.0
Capital goods	0.5	0.6	0.69	37.3	95.4	50.2
Construction	9.0	6.7	0.45	-	-	45.2
Private services	31.7	39.3	0.72	13.3	12.2	12.9
Public services	8.5	8.6	0.66	-	-	19.3
Sum/Average	100.0	100.0	0.61	18.2	22.6	24.3

As a starting point for the distribution of value added and factros, we used the distributions given in Condon et al. (1987), which differentiate between rural labor, unskilled labor, skilled labor and capital. These data, however, did not match our sectoral classification. In particular, wood processing, which we isolate in the model, is included in intermediates in the SAM reported there. We, therefore, reduced labor inputs and capital stock in intermediates in a way which kept wage rates and the rental rate constant and allocated them to wood processing.

There is no consistent data on markets for productive assets in Cameroon, and such markets are, in most cases, rudimentary. The data available from Condon et al. (1986) is for capital stock by sector, which is derived from figures on sectoral capital output ratios. Returns to capital in agriculture and forestry are higher than in other sectors. This can be seen as evidence that returns to land are implicitly incorporated in returns to capital in these sectors. A set of factor shares provided by the Ministry of Planning (Djophant, Tchounkoue, 1992) was used to divide gross operating surpluses between capital and land in agriculture and forestry. Complementary information on land use patterns were obtained from FAO (1981) and World Bank (1989). These figures are presented in Table 14.

3. Calibration of the Model

a. Parameters for the Forestry Growth Model

The growth characteristics of the Cameroonian forest are given by equations (1) - (3). These equations are parameterized as follows. The maximum stocking rate MV is set at 280 m^3/ha, equal to the average stocking rate in virgin portions of Cameroon's forests as reported in Amelung and Diehl (1992: Table 12). The current average stocking rate across all forests $TV(0)$ of 264 m^3/ha is calculated as the weighted average of stocking rates in virgin, exploited and unexploited forests using the respective areas as reported in FAO (1981) as weights. The maximum intrinsic growth rate is found by solving equation (2) for g, given MV = 280, TV = 264, and $\partial TV / \partial T$ = 1.0 cubic metres per year (FAO, 1981). The resulting value is g = 0.0704, equivalent to just over 7 percent. TV* was set a value of 260 m^3/ha, the average stocking rate across the whole forest when the logged portions are assumed to be stocked slightly lower than the average. With harvests reported to average 6 m^3/ha [FAO, 1988], this sets the value for TV at

TV = TV* + HARVEST = 260 + 6 = 266 m^3/ha.

Table 14 - Composition of Production Costs and Qualities of Primary Factors Used in the Reference Year 1979/80

Sector of Origin	Production costs	Intermediate inputs	Indirect taxes	GDP at factor costs	Distribution of Gross Factor Income			Distribution of Factor Inputs		
					Labor	Capital	Land	Labor (1000 man-years)	Capital (billions CFAF)	Land (10,000 ha)
1	330.49	19.97	0.66	309.85	203.7	40.5	65.7	1817.6	495.7	1412.8
2	106.34	61.24	-	45.11	27.0	13.2	4.9	450.3	170.9	101.4
3	29.49	9.40	1.68	18.41	3.4	0.6	12.3	10.1	7.7	200.0
4	18.78	10.68	0.96	7.14	3.8	3.4	-	6.9	37.6	-
5	190.45	123.12	14.09	53.24	31,1	22.1	-	93.1	376.9	-
6	265.59	168.79	6.37	90.42	36.5	53.9	-	36.3	815.6	-
7	34.17	20.64	0.48	13.05	6.5	6.5	-	3.4	102.5	-
8	10.30	2.92	0.30	7.08	5.0	2.1	-	7.1	20.6	-
9	174.11	89.62	5.92	798.58	39.3	39.3	-	58.2	435.3	-
10	615.78	123.06	46.80	445.91	133.8	312.1	-	308.9	769.7	-
11	163.96	55.47	-	108.49	86.0	22.5	-	115.8	180.4	-
Sum	1939.45	684.90	77.26	1177.29	576.1	516.2	82.9	2907.7	3412.9	1714.2

These values for TV, TV*, g and MV are substituted into equations (1) and (3)

$$T = -\frac{1}{0{,}0704} \cdot \ell n\left(\left[1-\frac{280}{266}\right] / \left[1-\frac{280}{264}\right]\right) \approx 2 \text{ years}$$

$$T^* = -\frac{1}{0.0704} \cdot \ell n\left(\left[1-\frac{280}{260}\right] / \left[1-\frac{280}{264}\right]\right) \approx -4 \text{ years}$$

to derive a value for the rotation period of

ROT = T-T* = 2 + 4 = 6 years.

b. Parameters for the Rest of the Model

In the calibration of the rest of the model, one uses the optimizing conditions of the producers' and consumers' decisions in the benchmark equilibrium in order to numerically fix a number of parameters. Particularly estimated values for substitution elasticities are taken from econometric studies if available. If not, these elasticities have to be estimated or more restrictive functional forms have to be chosen. For example, our usage of restrictive Cobb-Douglas production functions and Cobb-Douglas utility functions in the Cameroon model reflects the fact, that there are neither any estimates of more flexible supply and demand functions nor are there any reliable time series or cross-sectional data to estimate such functions.[19]

- Factor Income Proportionality Constants

The benchmark data set includes the value data on revenue flows that are needed to determine the parameters of the income/expenditure block of equations. First is the γ_{if}

[19] More recently, the Government of Cameroon carried out a household income and expenditure survey covering 5,000 households. However, the survey data was not entirely processed when the benchmark data set was constructed.

parameter in that block, which relates sector-specific factor returns to the economy-wide average factor returns (P_{if} / P_f). The benchmark data include data on factor payments by factor and sector. Coupled with data, on the sectoral quantity of each factor (workers, capital stock, land), both the sector-specific (P_{if}) and economy-wide average (P_f) factor returns can be calculated. For example, the sector-specific wage for rural labor equals a sector's wage bill for the labor category, divided by the number of rural workers employed. The average rural wage is the economy-wide rural wage bill divided by the total number of rural workers employed. The γ_{if} for each sector is the ratio of the sector-specific to the average rural wage.

The γ_{if} 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 or land quality across sectors that are not captured in capital stock or land data, or variations in the sectoral 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 homogenous and there were no rigidities or distortions.

The existence of such rigidities and distortions is reflected in the fact that the measured γ_{if} parameters differ from one. Moreover, by assuming that the structural characteristics responsible for these differentials are invariant to the question at hand, 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. Of course, simulations in which the γ_{if} parameters change, either exogenously or endogenously, are also possible, in order to analyze the impact that reducing (or increasing) distortions will have on the economy.

- Tax and Savings Rates

The next set of parameters to be determined include the institutional tax and savings rates. The benchmark data provide the values of total institutional 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 (net) income. The mapping from factor income into institutional income and finally into household income is quite simple in our model. More complex schemes can be adopted; however, as long as the institutions appear in the benchmark data then the tax and savings rates (and government transfers, foreign capital inflows, or other flows) are easily parameterized for use in the computer model.

- 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 (c^H)
- government final demand (c^G)
- investment allocation by sector of destination ($kshr_j$).

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

In the model intermediate goods are demanded in fixed proportions (the a_{ij} coefficients) defined in real terms (physical units of input per unit of output). Intermediate demand is for the composite good, which itself is a CES aggregation of imported and domestically produced 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 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, however, 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, since all capital goods have the same composition.

The household consumption demands c^H are defined as expenditure shares - the fraction of the household's total expenditure which is spent on good i. This formulation is consistent with an underlying Cobb-Douglas utility function, which will yield fixed sectoral expenditure shares. The government's consumption demands are defined in real terms, since total government expenditure is defined as a real variable. For a given real consumption level ($\overline{C}^G$), 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 nominal shares, which depend on the ratio of the sectoral to the average rental rate.[20]

- Trade Functions

Values for the parameters a_i^Q and δ_i^Q of the CES import aggregation functions [equation (26)] of our model can be calculated for given substitution elasticities σ_i^Q as follows. According to the first-order conditions of minimizing the demanders' cost [equation (27)], we get the result (dropping sector subscripts)

$$\frac{M}{D} = \left[\frac{P^d}{P^m} \cdot \frac{\delta^Q}{1-\delta^Q} \right]^{\sigma^Q}.$$

M and D are known from the data for the equilibrium in the reference year. Since the domestic prices $P^d = P^m = 1$ are applicable here, one can determine δ^Q according to

$$\text{DUMMY} = \frac{P^m}{P^d} \cdot \left[\frac{M}{D} \right]^{\frac{1}{\sigma^Q}}$$

$$\delta^Q = \text{DUMMY}/(1\text{-DUMMY})$$

[20] 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 capital stock.

The level parameter a^Q can then be calculated from the import aggregation function:

$$a^Q = Q / \left[\delta^Q \cdot M^{(\sigma^Q - 1)/\sigma^Q} + (1-\delta^Q) \cdot D^{(\sigma^Q - 1)/\sigma^Q} \right]^{\sigma^Q/(\sigma^Q - 1)}$$

The parameters of the export transformation function [equation (31)] can be computed in a similar way under the assumption that producers maximize their revenues from exports and domestic sales. The substitution elasticities σ_i^Q and transformation elasticities σ_i^T for the calibration of the foreign-trade equations were taken from Condon et al. (1987). These elasticities, together with the trade ratios and the resulting distribution parameters δ_i^Q and δ_i^T, and level parameters a_i^Q and a_i^T are reported in Table 15. This table also contains the export demand elasticities used to calibrate the export demand equation (51). Because in the reference year $P^{Se} = \overline{P}^{Se}$ it follows that $a^E = E$, irrespective of the chosen value for η.

- Cobb-Douglas Production Functions

The production elasticities (α_{if}) and the shift parameters (a_i^x) of the Cobb-Douglas production functions can be calculated as follows. According to the first-order conditions for cost minimization [equation (28')] we get

$$P_f \cdot (1 + t_{if}) \cdot \gamma_{if} = P_i^v \cdot \alpha_{if} \cdot \frac{X_i}{F_{if}}$$

X_i and F_{if} are known from the benchmark data and P_f, t_{if}, γ_{if} and P_i^v can be calculated from the benchmark data. In the first-order condition, only the share parameters are unknown. Thus the shares can be solved for directly:

$$\alpha_{if} = \frac{P_f \cdot (1 + t_{if}) \cdot \gamma_{if} \cdot F_{if}}{X_i \cdot P_i^v}$$

Table 15 - Parameters of the Foreign Trade Functions and Trade Shares in the Reference Year 1979/80

Sectors	Import Aggregation				Export Transformation				Export Demand
	σ_i^Q	a_i^Q	δ_i^Q	M/D	σ_i^T	a_i^T	δ_i^T	E/D	η_i
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1	1.50	1.103	0.037	0.01	1.50	5.722	0.945	0.01	1.0
2	0.90	1.984	0.571	1.27	0.90	4.997	0.035	15.77	1.0
3	-	-	-	-	0.40	2.793	0.055	3.12	1.0
4	0.50	1.199	0.010	0.10	0.50	2.399	0.856	0.41	4.0
5	1.25	1.804	0.297	0.34	1.25	2.607	0.796	0.18	4.0
6	0.50	1.978	0.395	0.81	0.5	2.163	0.758	0.56	4.0
7	0.75	1.840	0.728	2.10	0.75	2.224	0.747	0.44	4.0
8	0.40	1.081	0.999	20.85	0.40	2.168	0.786	0.59	4.0
9	-	-	-	-	-	-	-	-	-
10	0.40	1.237	0.007	0.14	0.40	4.246	0.991	0.15	4.0
11	-	-	-	-	-	-	-		-

Given that the data from the benchmark data set add up, total factor payments equal total value added in each sector. This in turn implies constant returns to scale or, equivalently, that the α_{if}'s sum up to one in each sector.

Once the factor shares are determined, only the shift parameters remain to be calibrated. Given factor inputs, share parameters and output, the a_i^x's can be calculated from the production functions as:

$$a_i^x = X_i / \Pi_f F_{if}^{\alpha_{if}}$$

The parameter of the Cobb-Douglas production functions are given in Table 16.

- CES Production Functions and LES Demand Functions

Whether the observed equilibrium alone is sufficient to uniquely determine the parameter values depends upon the functional forms used. The benchmark equilibrium data set, which contains equilibrium factor shares observations, can only be generated by Cobb-Douglas production functions. For CES production functions, however, extraneous estimates of elasticities of substitution are needed to determine the other parameters of the production functions.

Using these elasticities it is then possible to calculate the production function parameters from the benchmark equilibrium observations of capital, labor, and land services in each industry. We consider the case of the nested CES value added functions given in equations (22) - (24).

At the lower level, these functions are given by (dropping sector subscripts):

$$F_f = a_f^F \left[\Sigma_j \delta_{fj} \cdot F_{fj}^{(\sigma_f^j - 1)/\sigma_f^j} \right]^{\sigma_f^j/(\sigma_f^j - 1)}$$

Table 16 - Parameters of the Cobb-Douglas Production Functions in the Reference Year 1979/80

Sectors	Shift Parameter a_i^x	Factor Share Parameters α_{if}					
		Labor			Capital	Land	
		Rural	Unskilled	Skilled		Forest	Nonforest
1	0.287	0.598	0.059	-	0.131	0.008	0.204
2	0.764	0.483	0.055	0.061	0.292	0.024	0.084
3	10.978	0.450	0.105	0.351	0.094	-	-
4	2.615	0.263	0.061	0.205	0.470	-	-
5	2.711	0.105	0.116	0.363	0.415	-	-
6	1.991	0.048	0.058	0.298	0.596	-	-
7	3.713	0.078	0.070	0.352	0.500	-	-
8	2.961	0.121	0.110	0.470	0.300	-	-
9	2.389	0.092	0.116	0.291	0.500	-	-
10	1.606	0.042	0.044	0.215	0.700	-	-
11	1.292	-	-	0.792	0.208	-	-

where δ_{fj} is a weighting parameter, σ_f^j is the elasticity of substitution, F_{fj} are the factor inputs making up the aggregate factor F_f. According to the first-order condition for minimizing the cost of acquiring the factor aggregate we get (see equations (29) and (30):

$$\frac{F_{fj}}{F_f} = \left[\frac{P_f \cdot \delta_{fj}}{\gamma_{fj} \cdot P_j \, (1+t_{fj})} \right]^{\sigma_f^j}$$

or

$$\frac{\gamma_{fj} \cdot P_j \, (1+t_{fj}) \cdot F_{fj}}{P_f \cdot F_f} = (\delta_{fj})^{\sigma_f^j} \left[\frac{\gamma_{fj} \cdot P_j \, (1+t_{fj})}{P_f} \right]^{1-\sigma_f^j} .$$

The LHS is just the share of factor type j in total payments for the aggregate factor f which can be calculated from the benchmark data. If we let this be DUMMY 1 and let DUMMY 2 be the quantity

$$\left[\gamma_{fj} \cdot P_j \, (1+t_{fj}) \right]^{1-\sigma_f^j}$$

the above equation can be thrown into the form

$$\text{DUMMY 1} \cdot \text{DUMMY 3} = \left(\delta_{fj} \right)^{\sigma_f^j} \cdot \text{DUMMY 2}$$

in which

$$\text{DUMMY 3} = \left(P_f \right)^{1-\sigma_f^j}$$

These equations determine the quantities $\left(\delta_{fj} \right)^{\sigma_f^j}$ up to the scaling factor DUMMY 3, which can be determined by normalization. The most convenient one is $P_f = 1$ in the base year, in which case DUMMY 3 = 1 and

$$\delta_{fi} = \left[\frac{DUMMY1}{DUMMY2}\right]^{1/\sigma_f^i}.$$

Once the factor aggregates F_{if} are determined the parameters of the upper nest of the CES production equation (22) can be calculated in a way similar to that used to calculate the parameters of the import aggregation function, i. e., use the first-order condition [equation (28)] to derive the distribution parameters (δ_{if}^x) at given substitution elasticities (σ_i^x) and then calculate the efficiency parameter (a_i^x) from equation (22).

It would seem natural to carry the CES framework over to price substitution in consumer demand. However, CES functions are homothetic, displaying unitary elasticities of inputs with respect to output. Since income elasticities of demand for most goods differ from unity (Engel's Law) applied CGE models often incorporate the linear expenditure system (LES).

Given average budget shares (c_i) from the benchmark equilibrium data set, exogenously specified expenditure elasticities (ε_i), and an estimate of the money flexibility (ω),[21] the parameters of the LES can be calculated as follows. Given the average budget shares and expenditure elasticities, the marginal budget shares are given by

$$\beta_i = \varepsilon_i \cdot c_i$$

Note that the marginal budget shares sum up to one (Engel aggregation). The subsistence minima τ_i are related to the other parameters according to:

$$\tau_i = \frac{Y^H(1-s^H)(1-t^H)}{P_i} \cdot \left(c_i + \frac{\beta_i}{\omega}\right).$$

Given the parameters of the LES, the own- and cross-price elasticities of demand can be calculated as

$$\eta_{ii} = -\varepsilon_i \left(\frac{P_i \cdot \tau_i}{Y^H(1-s^H)(1-t^H)} - \frac{1}{\omega}\right) \quad \text{and}$$

[21] The money flexibility (often called "Frisch parameter") measures - roughly speaking - the intensity of change in expenditure patterns resulting from changes in the system of relative prices.

$$\eta_{ij} = -\varepsilon_i \left(\frac{P_i \cdot \tau_i}{Y^H (1 - s^H)(1 - t^H)} \right) \qquad i \neq j$$

By using the complete benchmark equilibrium data set in this way to generate parameter values for the trade, production, and demand functions, the equilibrium computed by the model before any policy changes will replicate the benchmark equilibrium data set exactly. This is assured as the equilibrium conditions have been used directly in the determination of parameter values.

Once the calibration procedure is completed, a fully specified numerical model is available that can be used for policy analysis. Any policy change can be considered and a counterfactual equilibrium computed for the new policy regime. Policy appraisal then proceeds on the basis of pairwise comparison of counterfactual and benchmark equilibria.

IV. Concluding Remarks

This paper has outlined a multisector general equilibrium model suitable for studying deforestation issues in tropical developing countries. We first described the theoretical structure of the model and then illustrated how the model can be calibrated to the base data for a particular country. Despite its unavailable notational complexity the model is simple and orthodox representing a straight forward extension of the CGE model framework developed by Dervis et al. (1982). As such it is tightly constrained by micro economic theory.

The structure of the model was dictated by four sets of considerations: the policy issues we wish to address; the potential instruments we wish to investigate; the theory relating instruments and targets; and the institutional and economic characteristics of the economies to be analyzed.

Empirical progress to date has involved the application of the comparative-static and comparative-dynamic version of the system to examine some of the short- to medium-term consequences of reducing deforestation in Cameroon in various ways [Thiele, Wiebelt, 1992, 1993]. The results are encouraging. The model provides orders of magnitude of the empirical relationship between environmental policy instruments (designed to reach the same increase in standing timber) and the macro economy, sectoral production, trade flows, land use patterns etc. as well as between economic policy instruments (trade policies) and the degree of deforestation and degradation. Greater understanding in this area could enhance the appreciation of the trade-offs associated with specific environmental policies and could help policy makers to integrate environmental concerns into economic objectives.

Subject to the model continuing to perform plausibly on a range of policy shocks with different model closures, its development will proceed with a view to implementing the model system to Brazil and Indonesia. In both countries, regional incentives were a major cause for deforestation in the past and call for a region-wise disaggregation of the model.

High on the agenda for future empirical work is the modification of the external-closure equation to show separate foreign capital inflows and the simulation of the effects of alternative compensatory foreign payment schemes. Experience to date suggests that such extensions will be relatively straight forward. By far the most difficult task in implementing the model will involve the construction of a suitable consistent data base and the estimation of key behavioural parameters. However, the work is worthwhile because the potential range of policy applications of such a model is enormous.

References

Amelung, T., M: Diehl (1992), Deforestation of Tropical Rain Forests: Economic Causes and Impact on Development. Kieler Studien, 242. Tübingen: J.C.B. Mohr.

Armington, P. (1969), A Theory of Demand for Products Distinguished by Place of Production. IMF Staff Papers 16, pp. 159-178

Binswanger, H.P. (1989), Brazilian Policies that Encourage Deforestation in the Amazon. Environment Department Working Paper, No. 16. Environment Department, The World Bank. Washington, D.C.

Bojö, J., K.-G. Mäler, L. Unemo (1990), Environment and Development: An Economic Approach. London: Kluwer Academic Publishers.

Bolton, R. (1988), Integrating Economic and Environmental Models: Some Preliminary Considerations. Research Paper Series, RP-126. Department of Economics, Williams College. Williamstown.

Condon, T., H. Dahl, S. Devarajan (1987), Implementing a Computable General Equilibrium Model on GAMS: The Cameroon Model. DRD Discussion Paper, Report No. DRD290. Development Research Department, The World Bank. Washington, D.C.

Dee, P.S. (1991 a), The Economic Consequences of Saving Indonesia's Forests. Working Paper Series, No. 91/7. National Centre for Development Studies. Canberra.

--, (1991 b), Modelling Steady State Forestry in a Computable General Equilibrium Context. Working Paper Series, No. 91/8. National Centre for Development Studies. Canberra.

Dervis, K, J. de Melo, S. Robinson (1982), General Equilibrium Models for Development Policy. Cambridge: Cambridge University Press.

Devarajan, S. (1990), Can Computable General Equilibrium Models Shed Light on the Environmental Problems of Developing Countries? Paper prepared for WIDER conference on "The Environment and Emerging Development Issues", Helsinki, September 1990.

--, J.D. Lewis, S. Robinson (1991), External Shocks, Purchasing Power Parity, and the Equilibrium Real Exchange Rate. Working Paper, No. 611. Department of Agricultural and Resource Economics, University of California of Berkeley. Berkeley.

Djophant, G., P.S. Tchounkoue (1992), Exploitation of Tropical Forest Resources as an Input Good for Agriculture and Forestry: Its Impact on Sectoral Production and Deforestation in Cameroon. Yaounde (mimeo.).

FAO (1981), Les Ressources Forestieres de l'Afrique Tropicale. Rome.

--, (1988), Tropical Forestry Action Plan. Rome.

Mahar, D. (1989), Government Policies and Deforestation in Brazil's Amazon Region. The World Bank. Washington, D.C.

Mansur, A., J. Whalley (1984), Numerical Specification of Applied General Equilibrium Models: Estimation, Calibration, and Data. In: Scarf, J.B. Shoven (Eds.), Applied General Equilibrium Analysis. New York: Cambridge University Press, pp. 69 - 127.

Muzondo, T.R., K.M. Miranda, A.L. Bovenberg (1990), Public Policy and the Environment: A Survey of the Literature. IMF Working Paper, WP /90/56. International Monetary Fund. Washington, D.C.

Nunnenkamp, P. (1992), International Financing of Environmental Protection: North-South Conflicts on Concepts and Financial Instruments. Kiel Working Papers, No. 512. Kiel Institute of World Economies. Kiel.

Pearce, D.W. (1990), An Economic Approach to Saving the Tropical Forests. LEEC Paper 90-06. London Environmental Economic Centre. London.

Powell, A., F. Gruen (1968), "The Constant Elasticity of Transformation Production Frontier and the Linear Supply System". International Economic Review, 9, pp., 315-328.

Repetto, R. (1988), The Forest for the Trees? Government Policies and the Misuse of Forest Resources. World Resource Institute. Washington, D.C.

Sato, K. (1967), "A Two-level Constant-Elasticity-of-Substitution Production Function". Review of Economic Studies, 34: 2, pp. 201-218.

Thiele, R., M. Wiebelt (1992), "Wirtschaftspolitische Optionen zur Begrenzung der Tropenwaldrodung - das Beispiel Kamerun". Die Weltwirtschaft, Heft 4.

--, M. Wiebelt (1993), Policies to Reduce Tropical Deforestation and Degradation. Paper prepared for the VII European Congress of Agricultural Economists on "Transition to an Integrated Agricultural Economy". Stresa, September 1993.

Wilen, J.E. (1985), Bioeconomics of Renewable Resource Use. In: A.V. Kneese, J.L. Sweeney (Eds.), Handbook of Natural Resource and Energy Economics, Vol. I. Amsterdam: North-Holland, pp. 61 - 124.

World Bank (1989), Cameroon Agricultural Sector Report. Washington, D.C.