COMPUTABLE GENERAL EQUILIBRIUM MODELS AND THE ANALYSIS OF POLICY SPILLOVERS IN THE FOREST SECTOR

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Environment Discussion Paper No. 19
July 1996

US EPA - CLIMATE CHANGE DIVISION
United States Environmental Protection Agency

This paper was sponsored by the Harvard Institute for International Development (HIID) under a cooperative agreement with the US Environmental Protection Agency (Climate Change Division).

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Acknowledgments: The authors would like to thank Brandi Sladek, Selena Rose and Jennifer Watts for technical assistance.

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1. INTRODUCTION

Researchers are increasingly aware of the impact of nonforestry policies, such as ones related to trade, interest rates, and taxes and subsidies, upon deforestation and forest degradation in developing countries. A review of forest economics commissioned by the World Bank observed that "policy spillovers are among the major causes of global deforestation" (Hyde et al. 1991, p. 37). There is also increasing recognition that forestry policies can affect the performance of nonforest sectors through environmental and economic linkages. For example, policies to develop forested uplands can reduce output in downstream agricultural sectors due to increased severity of floods. In economies with large, export-oriented forest sectors, forestry trade policies can conceivably affect the exchange rate and other macro variables.

Studies using a computable general equilibrium (CGE) approach to analyze these policy spillovers have appeared recently in the literature. CGE models simulate, for the entire economy, economic behavior in both goods and factor markets simultaneously. In a CGE model, supply and demand functions for goods and factors are explicitly derived from profit-maximizing behavior by producers and utility-maximizing behavior by consumers. Consumption and production quantities and relative prices are then determined endogenously. Compared to other economy-wide modeling techniques, such as input-output modeling, the CGE approach is characterized by its greater comprehensiveness, its stronger microeconomic foundations, its price-endogenous features, and its ability to accommodate nonlinear relationships and resource constraints. It has been extensively used to simulate macroeconomic policy changes and external shocks in both developed and developing countries.

This paper evaluates the usefulness of CGE models for analyzing the effects of sectoral and macroeconomic policies on deforestation and forest management. It consists of four sections. Following this introductory section, Section 2 reviews applications of CGE models to forest-related issues, summarizing the principal policy findings regarding deforestation and forest management. Section 3 provides a critique of those models and identifies areas in need of improvement. Section 4 presents an improved CGE framework for deforestation and forest management in developing countries. The proposed model carefully specifies various forest-related sectors or elements such as forestry production, deforestation, reforestation, forest land, forestry taxes and subsidies, timber trade, and property rights. Possible applications of the model to forest-related policy simulations are also suggested in that section.

2. REVIEW OF CGE APPLICATIONS TO FORESTRY POLICY ISSUES

Fifteen CGE models were reviewed for this study. These models represent most, if not all, CGE models that had been applied to forestry policy issues at the time of writing. Some are analytical, while others have been calibrated to data for specific countries and have generated empirical results.

One way to classify the models is according to their treatment of the forest sector. From that standpoint, they fall into three groups. The first, and largest, group includes models developed by Bergman (1990 and 1991), Panayotou and Sussangkarn (1991), Cruz and Repetto (1992), Dufournaud et al. (1992), Harrigan (1992), Coxhead and Jayasuriya (1994), Bandara and Coxhead

(1995), Coxhead and Shively (1995), and the Development Strategy Institute of Vietnam and the Harvard Institute for International Development (1995). These models represent applications of a standard, general-purpose CGE approach, with the forest sector being treated little differently than other production sectors. The second group recognizes the importance of the long growth period of trees and employs a steady-state formulation of the intertemporal forest harvesting problem. This group includes models developed by Dee (1991), Thiele and Wiebelt (1993), and Thiele (1995). The third group, which includes the models of Persson and Munasinghe (1995) and Persson (1995), explicitly specifies property rights and distinguishes among logging, squatter agriculture (e.g., shifting cultivation), and permanent agriculture.

Most applications of these models have been to the deforestation issue. Section 2.1 describes these applications, emphasizing forest-related features of the models. Section 2.2 then describes applications to other issues. Policy implications are summarized in Table 2-1. A detailed description of each model is presented in the appendix. The appendix also includes discussion of some CGE studies that have addressed nonforestry environmental issues (e.g., Girme 1992).

2.1 Applications to Deforestation

Panayotou and Sussangkarn (1991) develop a CGE model for Thailand to identify and analyze the implications of structural adjustment and related macroeconomic policies on Thailand's natural resource base and ambient environment. The CGE model is a standard one with 90 production sectors, including forest and wood processing sectors, and 3 production factors: land, labor, and capital. Land is separated into two types: land used for logging and land used in agriculture. The impacts of structural adjustment policies are estimated by multiplying input or output levels from policy simulations times fixed environmental parameters. For example, it is assumed (based on empirical evidence) that expansion of agricultural land results in a 1.4-times larger area of land deforested.

Cruz and Repetto (1992) and the Development Strategy Institute of Vietnam and the Harvard Institute for International Development (1995) also use standard CGE models to examine the environmental effects of stabilization and structural adjustment programs in the Philippines and Vietnam, respectively. Both models examine the impact of adjustment programs on forestry production, which in turn affects the disposition of forest land. The structure of the Vietnamese model is quite similar to the Thailand model of Panayotou and Sussangkarn.

Coxhead and Jayasuriya (1994) develop an analytical CGE model to assess the potential impact of technical progress on land use patterns in a simplified economy. The economy has two regions, upland and lowland, and three sectors, food crops, tree crops, and manufacturing. The upland region produces tree crops and food, while the lowland region produces food and industrial products. The two regions are linked through markets for food and labor. Bandara and Coxhead (1995) and Coxhead and Shively (1995) apply this framework to Sri Lanka and the Philippines to test the effects of macroeconomic policies on land-use patterns.

The analytical model of Dee (1991) is in the line of the ORANI model (see Dixon et al. 1982). It includes agriculture, mineral extraction, and forestry, all of which are land using, along with agricultural processing, mineral processing, wood processing, manufacturing, and services. The nonforestry sectors are represented by conventional single-period production functions, but the forestry sector is represented by a steady-state solution to the intertemporal harvesting problem. Two alternative treatments of land mobility are considered. In the first, land use in all industries is held fixed. In the second, land is mobile between agriculture and forestry, and it moves toward the use in which its discounted returns are greater.

Thiele and Wiebelt (1993) and Thiele (1995) investigate the effects of macro policies on deforestation in the Cameroon and Indonesia, respectively. Their models include a forestry submodel similar to Dee's. The optimal harvest age is derived by maximizing the present value of net returns from current and future harvests, at given timber prices, harvesting costs, interest rates, physical growth characteristics of trees, and a minimum harvest age of trees. Agricultural land and forest land are distinguished from each other, but they are assumed to be instantly interchangeable.

Persson and Munasinghe (1995) construct a seven-sector CGE model for Costa Rica. Among the sectors are logging, wood processing, squatter agriculture, and permanent agriculture. Besides specifying logging and squatter sectors, the model also differs from standard CGE models in two important respects. First, it includes two alternative forms of property rights: undefined and well-defined. This enables it to simulate the effects of the introduction of well-defined property rights. Second, it includes explicit markets for logs and cleared land. Logs are harvested by the logging sector and sold to the forestry sector. Cleared land is supplied by squatters only, and it is used by the permanent agriculture sector.

The static CGE model of Persson and Munasinghe (1995) is extended by Persson (1995) into a two-period intertemporal CGE model, also applied to Costa Rica, with endogenous savings and investment. The intertemporal nature of the model is reflected in the behavior of both producers and consumers. When property rights for forest land are undefined, the squatter or logging company 'owns' the land only for one period, and thus has no incentive to conserve forests. In that case, the behavior of a squatter or a logging company is the same as in the static model. When property rights are well-defined, the squatter and the logging company own the land in both periods. They then face an intertemporal maximization problem and make decisions by maximizing the present value of utility in both periods.

In contrast to the preceding models, which focus on logging and agriculture as causes of deforestation, Dufournaud, Quinn, and Harrington (1992) investigate the impacts of energy policies on the clear-cutting of scrub for firewood in Sudan. Their model contains seven sectors plus a 'domestic work' sector. It distinguishes between gathered and purchased wood, with gathered wood being supplied by the 'domestic work' sector.

Table 2-1 lists policies predicted by these studies to exacerbate or reduce deforestation.

Additional information is provided in the appendix. Many of the impacts are what one would expect on the basis of a partial-equilibrium analysis of the forest sector. Several are not, however, and it is these findings that indicate the ability of CGE models to shed new light on the ultimate impacts of nonforest policies upon forest resources. For example, Persson and Munasinghe (1995) find that a decrease in output taxes on agricultural products can reduce deforestation by promoting industrial expansion (due decreased pressure on wages and decreased cost of agricultural inputs). Similarly, Persson (1995) finds that agricultural subsidies can reduce deforestation, at least initially. Thiele and Wiebelt (1993) find that trade liberalization resulting in higher prices for logs can reduce deforestation, even though it increases logging activity, because it raises the value of forest land. The models also reveal unanticipated impacts of forest-sector policies. For example, Dufournaud et al. (1992) find that the introduction of more efficient wood stoves can increase deforestation by raising fuelwood consumption. Persson and Munasinghe (1995) and Thiele and Wiebelt (1993) find that higher stumpage fees can increase deforestation by causing labor and capital to shift toward agriculture. Thiele and Wiebelt (1993) also find that forestry protection policies can increase deforestation by reducing the commercial value of forest land.

These surprising results reflect the ability of CGE models to capture interactions between sectors and between goods and factor markets, and second-round effects related to changes in income and expenditure. Because CGE models make economic linkages explicit, the results can be explained by reference to the models' structure. CGE models yield not only predictions about the ultimate impacts of policies, but also detailed information on how those impacts result from multiple interactions that offset or accentuate each other.

2.2 Applications to Other Issues

Applications of the models described above yield results in addition to ones directly related to deforestation. For example, Dee (1991) finds that forest protection in Indonesia decreases real GDP (excluding nonmarket values of forests), but the decrease does not necessarily fall on the rural poor. Similarly, Persson (1995) finds that forest protection in Costa Rica decreases utility and increases the prices of land and capital. Policies to increase the length of forest leases, increase the stipulated minimum harvest age of trees, establish national parks, and tax income from forest land all raise the domestic price level in the Cameroon, according to Thiele and Wiebelt (1993).

A study by Harrigan (1992) focuses explicitly on the spillover of forestry policies into the rest of the economy. Using a model called M4, Harrigan measures the possible costs of an abatement of logging on the Malaysian economy. M4 includes thirteen sectors, one of which is a forestry sector with logging activities. Although most of the behavioral relationships in M4 are derived from static optimizing behavior, the model is specified to be in a steady state in order to simulate changes in the economy over time. Among a broad range of assumptions made for the model simulations, the flow of output from the forestry sector is assumed to be exogenously given (e.g., determined by sustained-yield forestry policies). Changes in the economy due to an abatement of logging activities can therefore be observed by comparing simulation results with and without log production. Abatement of logging is found to have a large negative impact on economic output, due to losses in foreign exchange earnings and government revenue.

Bergman (1990 and 1991) estimates the impact of nonforestry environmental policies, specifically air pollution emission control policies, on sectoral economic performance in Sweden, including performance of the forest sector. The forest sector is treated as an aggregate of wood production and pulp and paper industries. With the use of this model, growth of sectors in the Swedish economy from 1985 to 2000 is simulated under scenarios with and without constraints on air pollution emissions. The impact of air pollution control on the output of the forestry industry is found to be very small.

3. CRITIQUE OF CGE APPLICATIONS TO FORESTRY POLICY ISSUES

Although the models reviewed in Section 2 represent an advance in macroeconomic modeling of forestry issues, the models are still at an early stage, with much to be learned in terms of both methods and policy implications. This section provides a critique of the models. The intention is to identify opportunities for improvement, in order to develop a CGE modeling framework better suited for simulating the impacts of sectoral and macroeconomic policies upon forest resources.

Two limitations of the models are typical of CGE models. One is that they are weak in capturing dynamic aspects of an economy. Most are static models that omit investment relationships, population growth, and resource dynamics. In effect, they predict changes in economic conditions at a given point in time, holding the levels of dynamic variables (capital, labor, resource stocks) constant. This limitation is particularly serious when one examines forestry issues, which are dynamic along several dimensions: forest resources can grow and be depleted, are exploited by industries that entail substantial capital investments, offer land for agriculture to feed growing populations, and provide multiple benefits whose relative values change with development. Only a couple of the models have a dynamic flavor, and even they take shortcuts to avoid modeling dynamic processes directly. For example, Persson's (1995) model treats forest harvesting as a two-period intertemporal problem, while Dee (1991) specifies forest growth using a steady-state formulation. There is much room to improve these models by incorporating a wider range of dynamic features.

The other generic limitation is that all the empirical models are calibrated to a one-year data set by assuming functional forms and values of key elasticities. This approach is likely to lower the reliability of the simulation results because of the high probability that data for a single year do not reflect "average" conditions and that the functional forms and elasticities misrepresent actual behavioral relationships. It would be better to compile time-series data and estimate key relationships econometrically.

The modeling framework presented in the next section does not overcome these limitations. Instead, it attempts to address forestry-specific limitations. The major limitation of this type is that the models often fail to capture important linkages among the forest sector, agriculture, and the rest of the economy. As mentioned earlier, most of the models involve no more than simple modifications of a standard CGE modeling approach. They treat supplies of production factors, including land and natural resources, as fixed rather than endogenously determined, and they pay little attention to unique features of the forestry sector. In particular, they represent relationships among forest land, agricultural land, and other types of land poorly, if at all. Land is not included as a factor of production in the logging and squatter sectors of Persson's and Munasinghe's (1995) model. Dee (1991) treats forest land and agricultural land as easily interchangeable, ignoring the effect of the long growth period of trees on the conversion of agricultural land back to forest land. None of the models includes an explicit representation of reforestation activities. While any model must necessarily omit certain real-world features for the sake of tractability, land is such a key input to the forest sector that its omission severely compromises the ability of CGE models to investigate deforestation and forest management issues.

The negative impacts of deforestation and forest degradation on environmental quality, economic output, and social welfare are also left out. Several models (e.g., Dee 1991 and Harrigan 1992) measure the economic costs of forest conservation, but none attempts to incorporate the environmental benefits of forest conservation. Hence, it is not surprising that the models generally predict that conservation has negative macroeconomic consequences. Environmental services that significantly affect production and consumption behavior ought to be included in CGE models. Here, of course, the limitation is one of data, as most quantitative information on environmental benefits is from micro-level valuation studies.

Constructing a CGE model of an economy with forest resources is not easy, as the model must incorporate a number of variables and relationships specific to the forest sector yet link them to other sectors of the economy. Key factors of production include the stocks of forest land and standing timber, and key activities include deforestation (caused by logging and agriculture), reforestation, production of forest-based products (logs, firewood, processed wood products, etc.), and production of agriculture, energy, tourism, and other sectors that might be sensitive to the level of environmental services provided by forests. The area of forest land constrains the output of logs and other forest products and the scope for agricultural expansion. The area of forest land changes over time, being positively affected by reforestation and negatively affected by deforestation. These processes, along with harvesting and forest management, also affect the stocks of standing timber and other forest products. The logging sector supplies timber for forest industries, and squatter and permanent agriculture clear land for crop production and sell degraded land for reforestation. These sectors compete with each other and with other sectors for not just land but also labor and capital. In addition to land and timber (and other tangible forest products), the forest sector also provides inputs to other sectors and households in the form of nonmarket environmental services.

The many ways in which forest and nonforest sectors interact with each other are, of course, the source of multiple potential policy spillovers. In the remainder of this paper, we propose a CGE modeling framework that attempts to incorporate these interactions more completely and consistently than previous models have.

4. A GENERAL CGE FRAMEWORK FOR ANALYZING FORESTRY POLICY ISSUES

This section develops a general CGE framework for analyzing the effects of sectoral and macro policies on deforestation and forest management, as well as the impacts of forestry policies on the rest of the economy. The model is steady-state and pertains to a small (price-taking) open economy. It is different from standard CGE models in several respects. First, it distinguishes forest land from agricultural land and other production factors. Second, it carefully specifies forest-related activities, including deforestation and reforestation. Third, it includes forest-specific policy and regulatory instruments like timber charges, forestry subsidies, timber trade taxes, and property rights. Finally, it contains variables measuring the level of environmental degradation, and it uses these variables to capture the impacts of deforestation on production in other sectors and on social welfare. These variables include one related to greenhouse gas emissions.

The model includes four categories of economic agents: producers, consumers (a single representative household), government, and the rest of the world. Along with permanent agriculture, energy, and manufacturing sectors, it includes five forest-related sectors: logging, fuelwood collection, wood processing, squatter agriculture, and reforestation. Fuelwood collection, squatter agriculture, and reforestation produce nontradable goods. The remaining sectors produce tradable goods, with both imports and exports. Output of the logging sector is an intermediate good, logs (G), which is either used as an input by the wood-processing sector or exported.

The model includes three production factors: labor (L), capital (K), and land (U). Land resources are divided into five categories: forest land (FU), permanent agricultural land (AU), squatter land (QU), degraded or abandoned land (DU), and other land (OU). Land degradation results from both forms of agriculture (DU_a, DU_q) and from logging (DU_g). Deforestation results from demand by both forms of agriculture for cleared land (increases in AU and QU) and from degradation caused by logging (DU_g). Relationships among the different types of land are discussed more below.

The model distinguishes between high CO_2-intensive energy (EH; e.g., coal) and low CO_2-intensive energy (EL; e.g., hydropower). Unlike fuelwood, which is assumed to be consumed only by households, EH and EL are primarily used as production inputs, in the form of aggregate energy (AE). Classifying energy in terms of its CO_2 emission intensity permits analysis of the impact of energy-related policies on CO_2 emissions.

For simplicity, the model assumes that government has only two functions, tax collection and subsidy provision. Simplicity is also enhanced by leaving savings and investment out of the model. Procedures exist in the CGE literature for more realistic treatment of these aspects of a macroeconomic system, which we ignore as they are not the focus of this paper.

Table 4-1 lists the production sectors and their factor inputs, and Figure 4-1 displays major links among the sectors. This table and figure do not show externalities related to environmental degradation, which are included in the model by depreciating the productivity of factor inputs (discussed below). Detailed descriptions of the equations in the model are given in the following sections.

4.1 Output Supply

As illustrated in Figure 4-2, sectoral production functions take the form of nested constant elasticity of substitution (CES) and Leontief production functions. At the bottom layer are CES aggregations for value added (labor and capital; VA) and aggregate energy (AE). Value added and aggregate energy are then combined, also by means of a CES aggregation function, to form a composite factor (CF). In general terms, these bottom layers can be written as:

(1)	Composite factor:	$CF_i = CF_i(VA_i, AE_i)$
(2)	Value-added:	$VA_i = VA_i(L_i, K_i)$
(3)	Aggregate energy:	$AE_i = AE_i(EH_i, EL_i)$,

where $CF_i(\bullet)$, $VA_i(\bullet)$ and $AE_i(\bullet)$ are CES functions. In the case of squatter agriculture and fuelwood collection, the composite factor is just a function of labor, as those sectors are assumed not to use capital and energy.

A Leontief production function is adopted for the top layer of the nested production function. Output (XD_j) can then be computed by multiplying the composite factor, or land or logs (if they are inputs), times the corresponding fixed coefficient. This approach implies that there are no substitution possibilities between the composite factor and land or logs in permanent agriculture, squatter agriculture, fuelwood collection, logging, wood processing, and reforestation. This simplifies the model and is probably not a bad assumption for short-run behavior. The top layer could alternatively be specified as a CES function if the scope for substitution is thought to be empirically significant.

Choosing land as the input for computing output of permanent agriculture, squatter agriculture, and logging, and logs as the input for computing wood processing, we have:

(4a)	Permanent agriculture:	$XD_a = a_{au}AU$
(4b)	Squatter agriculture:	$XD_q = a_{qu}QU$
(5)	Logging:	$XD_g = a_{gu}(FU - FU_{park})/(T-T^*)$
	where: FU_{park} is forest land classified as parks,	
	T is the harvest age of trees,	
	$T-T^*$ is the cutting cycle	
(6)	Wood processing:	$XD_f = a_{fg}G$.

The output of the permanent and squatter agriculture sectors is crops, the output of the logging sector is logs, and the output of wood processing is wood products. The specification of equation (5) implies a steady-state solution to the timber harvest problem, along the lines of Dee's (1991) formulation. The number of age classes in a forest stand is given by $T/(T-T^*)$. If $T^*=0$, the silvicultural system is even-aged (e.g., clear-cutting or shelterwood; one age class); if $T^*>0$, the system is uneven-aged (e.g., a selection system; multiple age classes). T must be an integral multiple of T^*.

The model endogenously determines the value of coefficients related to the productivity of forest land, because those coefficients are affected by policy variables like T and T^*. As indicated in Figure 4-3, the gross harvest of forest land can be decomposed into three components: logs, fuelwood, and wood loss (wood that is damaged or is not useful as logs or fuelwood). Correspondingly, the technical coefficient of gross wood harvest (a_{wu}) can be decomposed into three coefficients. The log production coefficient in equation (5) (a_{gu}) is one of them; the others are the coefficient for fuelwood collection (a_{fwu}) and the coefficient for wood loss (a_{lu}). All coefficients are expressed in terms of cubic meters per hectare logged. The gross harvest coefficient is ecologically determined as a function of T and T^*:

(7) Gross harvest coefficient: $a_{wu} = A_1(T,T^*)$,

where $A_1(\bullet)$ is a function. This specification implicitly assumes that forest land is uniform; this assumption can be relaxed by adding FU as a variable (e.g., the coefficient declines with forest area, due to conversion of better land to agriculture). The log production coefficient includes the effect of technology (tech) on logging productivity:

(8) Log production coefficient: $a_{gu} = A_2(T,T^*, tech)$,

where $A_2(\bullet)$ is a function. As in (7), FU could be added to reflect higher logging costs as forest area shrinks (and logging is pushed to less accessible and steeper areas). The fuelwood production coefficient is equal to fuelwood output divided by logged area:

(9) Fuelwood collection coeff.: $a_{fwu} = Xd_{fw}/[(FU\text{-}FU_{park})/(T\text{-}T^*)]$.

This formulation implies that fuelwood is collected only in the logged-over area. It allows the intensity of fuelwood collection to vary (e.g., to be lower in higher income countries). a_{fwu} is a constrained to be less than or equal to the difference between a_{wu} and a_{gu}. Finally, the wood loss coefficient is computed residually:

(10) Wood loss coefficient: $a_{lu} = a_{wu} - a_{gu} - a_{fwu}$.

This coefficient is used to estimate CO_2 release from the decomposition of wood that is not used for logs or fuelwood.

4.2 Input Demands

Input demands are derived from the profit maximization criterion, that producers utilize a production input until the input price equals the marginal value product:

$$PF = (\partial XD/\partial F)PX,$$

where PF is input price, $\partial XD/\partial F$ is the partial derivative of the production function with respect to input F, and PX is output price.

Consequently, input demand functions for labor, capital, energy, land, and logs are given by:

(11)	Value-added:	$PVA_i = (\partial XD_i/\partial VA_i)PX_i$
(12)	Aggregate energy:	$PAE_i = (\partial XD_i/\partial AE_i)PX_i$
(13)	Capital:	$W_k = (\partial VA_i/\partial K_i)PVA_i$
(14)	Labor:	$W_l = (\partial VA_i/\partial L_i)PVA_i$
(15)	High-CO_2 energy:	$PEH = (\partial AE_i/\partial EH_i)PAE$
(16)	Low-CO_2 energy:	$PEL = (\partial AE_i/\partial EL_i)PAE$
(17a)	Perm. agr. land:	$PAU = a_{au}PX_a$
(17b)	Sq. agr. land:	$PQU = a_{qu}PX_q$
(18a)	Forests (logging):	$PFU_g = (a_{gu}PX_g)/(T\text{-}T^*)$
(18b)	Forests (fuelwood):	$PFU_{fw} = (a_{fwu}PX_{fw})/(T\text{-}T^*)$
(19)	Logs:	$PG = a_{fg}PX_f$

where PVA, PAE, W_k, W_l, PEH, PEL, PAU, PQU, PFU, and PG are prices of value added, aggregate energy, capital, labor, high-CO_2 energy, low-CO_2 energy, permanent agricultural land, squatter agricultural land, forest land, and logs, respectively. Input demand functions with these forms must be included in the model for all the sector/input combinations in Table 4-1.

Because Leontief input/output coefficients are employed to represent the relationships between output and land or log input, the demand functions for land in agriculture, logging, and fuelwood collection, and logs in wood processing, are unit-price equations (equations 17 to 19). The demand for land and logs is nevertheless bounded by total supplies of land and logs, which are given in the market-clearing block (discussed below). The total price received by owners of forest land in a competitive market is the sum of PFU_g and PFU_{fw}.

Deforestation can reduce the productivity of inputs. For example, deforestation might cause soil erosion that reduces the productivity of agricultural land. The negative impact of deforestation on a production input can be included by replacing the actual supply of an input with the *effective* supply. The effective supply can be modeled by using an environmental quality index to depreciate the factor stock. We discuss this point in section 4.7.

4.3 Trade

Trade is treated in the conventional way for CGE models. Within each sector, domestic goods sold locally and goods that are imported or exported are assumed to be imperfect substitutes. CES functions are employed to model imperfect substitution. The relationships among domestic and traded goods are shown in Figure 4-4, and can be summarized as follows. To begin, imports (M) and sales of domestic goods (XXD) are aggregated into a composite consumption good (X) using a CES function (this kind of function is frequently called an Armington function; see Armington 1969):

(20) Composite consumption: $X_i = X_i(M_i, XXD_i)$.

The expression on the right-hand side of this and each of the following three equations is a function. Import shares can then be derived by minimizing the costs of expenditure on composite goods:

(21) Import share: $M_i/XXD_i = M_i(PD_i/PM_i)$.

This specification indicates that an increase in the price of imports (PM) relative to the price of domestically produced goods (PD) decreases the share of imports in domestic consumption. Similarly, sectoral output (XD) can be defined as a composite production good by using a constant elasticity of transformation (CET) function to combine exports (E) and domestic sales (XXD), and export shares can be expressed as a function of relative prices in the international and domestic markets:

(22) Composite production: $XD_i = XD_i(E_i, XXD_i)$

(23) Export share: $E_i/XXD_i = E_i(PE_i/PD_i)$.

The export share is derived by maximizing revenue for a given level of output, under the constraint of the CET function.

For the nontradable sectors (squatter agriculture, reforestation, fuelwood collection), import and export terms are set to zero, so that composite consumption (X_i) simply equals domestic output (Xd_i).

4.4 Prices

There are four groups of prices in the model, in addition to the input prices defined in Section 4.2: trade prices; composite production, consumption, and energy prices; value-added prices; and land and log prices. The relationships among these prices are illustrated in Figure 4-5 and are described in the following paragraphs.

The world prices of imports and exports (PWM_i and PWE_i, respectively) are exogenously fixed under the small-country assumption. Hence, the domestic prices of imports (PM_i) are the world prices in domestic currency ($R\ PWM_i$) plus the tariff on a unit of imports:

(24) Import prices: $PM_i = R\ PWM_i\ (1+tm_i)$.

In this equation, R is the exchange rate, and tm_i is the tariff rate. Similarly, the domestic prices of exports (PE_i) are defined as:

(25) Export prices: $PE_i = R\ PWE_i / (1+te_i)$,

where te_i is the export tariff rate.

The prices of composite production (PX_i) and composite consumption (P_i) are defined as weighted averages of domestic and world prices:

(26) Composite production prices: $PX_i = (PE_i\ Ei + PD_i\ XXD_i) / XD_i$

(27) Composite consumption prices: $P_i = (PM_i Mi + PD_i\ XXD_i) / X_i$.

The price of aggregate energy is defined similarly:

(28) Aggregate energy price: $PAE_i = (PEH\ EH_i + PEL\ El_i)/AE_i$.

The prices of the two types of energy (PEH and PEL) are assumed to be uniform across sectors.

Value-added prices (PVA_i) are calculated by dividing value-added by output. Value-added is defined as total cash inflow — the sum of product sales revenue ($PX_i\ XD_i$) and government subsidies (SUB_i) — minus expenditure on taxes and inputs other than labor and capital. For manufacturing and the two energy sectors, expenditure includes payments for energy inputs ($PAE_i\ AE_i$) and indirect taxes (tc_i):

(29a) VA price, manufacturing and high-CO_2 and low-CO_2 energy (i=m,eh,el):

$$PVA_i = [PX_i\ XD_i + SUB_i - PAE_i\ AE_i - tc_i\ PX_i\ XD_i] / XD_i.$$

Other sectors include additional sources of income besides sales revenue and subsidies, and additional expenditure items besides aggregate energy and indirect taxes. The only difference between the wood processing sector and other forms of manufacturing is the addition of the cost of log inputs (PG G):

(29b) VA price, wood processing (i=f):

$$PVA_f = [PX_f\ XD_f + SUB_f - PAE_f\ AE_f - tc_f\ PX_f\ XD_f - PG\ G] / XD_f.$$

For permanent agriculture, income includes sales of degraded land to the reforestation sector ($PDU\ DU_a$), and expenditure includes property tax payments (tp AU) and payments of land rent (PAU AU):

(29c) VA price, permanent agriculture (i=a):

$$PVA_a = [PX_a\ XD_a + SUB_a + PDU\ DU_a - PAE_a\ AE_a - tc_a\ PX_a\ XD_a - tp\ AU - PAU\ AU] / Xd_a.$$

The value-added price for squatter agriculture is defined analogously, with the modification that receipts from sales of degraded land and payments of property taxes and land rents are multiplied by a parameter, δ_q, that measures the degree of property right attenuation:

(29d) VA price, squatter agriculture (I=q):

$$PVA_q = [PX_q\ XD_q + SUB_q + PDU\ DU_q - tc_q\ PX_q\ XD_q - \delta_q\ tp\ QU - \delta_q\ PQU\ QU] / Xd_q.$$

δ_q equals 1 if property rights are completely nonattenuated (fully secure), and 0 if they are completely attenuated (open access). When property rights are completely attenuated, squatters pay nothing for the land they clear and cultivate. The model assumes that squatters do not harvest and sell timber, so the equation includes neither income from log sales nor payments of stumpage fees.

As in the two agricultural sectors, the value-added price in the logging sector includes income from sales of degraded land to the reforestation sector ($PDU\ DU_g$). On the expenditure side, it includes forest rent payments based on area logged ($PFU\ (FU-FU_{park})/(T-T^*)$), and royalties on extracted logs ($ts\ a_{gu}\ (FU-FU_{park})/(T-T^*)$):

(29e) VA price, logging (i=g):

$$PVA_g = [PX_g\ XD_g + SUB_g + PDU\ DU_g - PAE_g\ AE_g - tc_g\ PX_g\ XD_g - PFU_g\ (FU-FU_{park})/(T-T^*) - ts\ a_{gu}\ (FU-FU_{park})/(T-T^*)] / Xd_g.$$

The reforestation sector must pay for the degraded land it reforests (PDU DU):

(29f) VA price, reforestation (i=r):

$$PVA_i = [PX_i\ XD_i + SUB_i - PAE_i\ AE_i - tc_i\ PX_i\ D_i - PDU\ DU] / Xd_i.$$

The only expenditure item in the value-added price for fuelwood collection is the payment of forest rent, which is subject to a property rights parameter:

(29g) VA price, fuelwood collection (i=fw):

$$PVA_i = [PX_i\ XD_i + SUB_i - \delta_i\ PFU_i\ (FU-FU_{park})/(T-T^*)] / XD_i.$$

Degraded land is assumed to have no productive value, other than for reforestation. Since the model is a steady-state model, the area reforested is assumed to equal the area of degraded land:

(30a) Reforestation equilibrium: $XD_r = DU$,

where:

(30b) Degraded land identity: $DU = DU_a + DU_q + Du_g$.

In effect, the supply curve for degraded land is vertical, implying that the price of degraded land can be determined by solving equation (29f) for it as residual. The reforestation sector sells its product, i.e., reforested land (XD_r), at the price of forest land:

(31) Price of reforested land: $PX_r = PFU$,

where, as discussed earlier:

(32) Price of forest land: $PFU = PFU_g + PFU_{fw}$.

Finally, the purchasing price of logs in the wood processing sector (PG) is equal to the output price of the logging sector (Px_g):

(33) Price of logs: $PX_g = PG$.

4.5 Income and Final Demand

The model assumes that the representative household is the sole provider of labor and capital and is the owner of agricultural land (including squatter land). Hence, household income (Y) is the sum of value added, government subsidies to households (HSUB), and land rents:

(34) Household income:
$$Y = \sum_i PVA_i\ XD_i + HSUB + PAU\ AU + PQU\ QU.$$

Government revenue is defined as the sum of revenue from indirect taxes (tc), import tariffs (tm), export taxes (te), property taxes (tp), stumpage taxes (ts), and forest rents (the government is assumed to be the owner of forests):

(35) Government revenue:
$$GR = \sum_i [PX_i\ XD_i\ tc_i + PM_i\ M_i\ tm_i + PE_i\ E_i\ te_i] + tp\ AU + ts\ a_{gu}\ (FU\text{-}FU_{park})/(T\text{-}T^*) + PFU\ (FU\text{-}FU_{park})/(T\text{-}T^*).$$

Government revenue is spent on only three components, government subsidies to enterprises (SUB_i) and households (HSUB), and government payments to the reforestation sector for reforested land:

(36) Government expenditure: $GR = \sum_i SUB_i + HSUB + PFU\ Xd_r$

The government subsidy to a specific production sector is a fixed share (c_i) of total expenditure on production subsidies:

(37) Production subsidies: $SUB_i = c_i(GR - HSUB - PFU\ Xd_r)$,

where c_i is a fixed share and $\sum_i c_i = 1$.

Household demand for a specific good (CD_i) is derived from the household's utility maximization problem, with the utility function assumed to have a Cobb-Douglas form. Hence, expenditure on a specific good is a fixed proportion to household income:

(38) Household demand: $CD_i = b_i\ Y / P_i$.

4.6 Equilibrium Conditions

In equilibrium, production and consumption of goods must equal each other, as must production and consumption of factor inputs. For goods, we have:

(39) Goods equilibrium (I=a,q,m,f,fw):
$X_i = CD_i$
(40) Goods equilibrium (I=g): $X_g = CD_g + G$
(41) Goods equilibrium (I=eh): $X_{eh} = CD_{eh} + \sum_j EH_j$
(42) Goods equilibrium (I=el): $X_{el} = CD_{el} + \sum_j Eh_j$.

The last three conditions, which are for logs and the two forms of energy, include intermediate consumption as well as household consumption. Equilibrium in the land market, including for reforested land (X_r, which is not consumed by households), will be discussed in a moment.

Turning to factors, aggregate labor demand ($\sum_i L_i$) equals labor supply (LS) less unemployment, where R_{unemp} represents the unemployment rate:

(43) Labor equilibrium: $\sum_i L_i = LS\ (1-R_{unemp})$.

LS is exogenously fixed. There are two ways to close this equation. One is to allow the wage rate (W_l) to adjust to a given unemployment rate (R_{unemp}). The other is to fix the wage rate and allow the unemployment rate to adjust. Capital market equilibrium is simpler:

(44) Capital equilibrium: $\sum_i K_i = KS$,

where KS is the capital stock (exogenously fixed). The price of capital (W_k) adjusts to balance supply and demand.

As discussed earlier, land resources are classified into five categories: AU, QU, FU, DU, and OU. Figure 4-6 illustrates the relationships among these categories. The equilibrium condition for land resources is:

(45) Land equilibrium: $TU = AU + QU + FU + DU + OU$.

The total area of land (TU), and area of other land (OU), are exogenous. Creation of degraded land is proportional to the amount of land farmed and logged:

(46) Degraded land, perm. agr.: $DU_a = a_{da}\ AU$
(47) Degraded land, sq. agr.: $DU_q = a_{dq}\ QU$
(48) Degraded land, logging: $DU_g = a_{dg}\ (FU\text{-}FU_{park})/(T\text{-}T^*)$.

DU_a, DU_q, and DU_g are all flow variables, in constrast to AU, QU, FU, DU, and OU, which are stock variables. As mentioned earlier, equilibrium conditions related to degraded land are:

(30a) Reforestation equilibrium: $XD_r = DU$
(30b) Degraded land identity: $DU = DU_a + DU_q + Du_g$.

All degraded land is reforested, so the model is in a steady state. That is, flows that increase forest area exactly offset flows that decrease forest area. The model therefore predicts equilibrium forest areas consistent with given stocks of factors of production (land, labor, capital) and given prices and policies. In Figure 4-6, $\vartriangle$AU and $\vartriangle$QU indicate changes in agricultural areas between scenarios (i.e., equilibrium changes in response to policy or external shocks).

The final equation needed to ensure equilibrium is the balance of trade:

(49) Balance of trade: $\sum_i PM_i\ M_i = \sum_i PE_i\ E_i + BOP$

BOP is the trade deficit (more on this in Section 4.8).

4.7 Externalities of Deforestation

Deforestation externalities such as flooding, climate change, and loss of biological diversity are important forms of environmental degradation that reduce output and welfare. Production externalities can be incorporated by reducing the productivity of labor and capital inputs in affected sectors. For example, the labor input in a production function can be replaced by:

(50) Effective labor input: $LE_i = L_i\ D_i(FU)$,

where $D_i(FU)$ is a function of the area of forest. Similarly, effective capital input can be defined as:

(51) Effective capital input: $KE_i = K_i \, Z_i(FU)$.

Consumption externalities (e.g., the amenity value of forests, the existence value of biodiversity) can be incorporated by including the area of forest in the utility function:

(52) Forest-inclusive utility: $UTIL = U_c(CD_a, CD_m, ...) \, U_f(FU/TU)$.

The level of utility (UTIL) reflects satisfaction from households' consumption of goods (the function U_c) and forest-related consumption externalities (the function U_f). If a Cobb-Douglas function is adopted to measure the utility gain from household consumption of goods, then the exponents in that function are just the b_i parameters in equation (38). U_f can be constructed to yield an index ranging from 0 (no forests) to 1 (no land other than forest).

Because energy is classified according to its carbon dioxide intensity, and the model contains considerable detail on the forest sectors and land use, the model can be used to examine the effects of macro policies on carbon sequestration and emissions. As the forest is in a steady state, net CO_2 emissions simply equal emissions from consumption of energy other than fuelwood:

(53) Net CO_2 emissions: $W = F_1(XD_{eh}, Xd_{el})$,

where F_1 is a function. The amount of carbon sequestered in the forest depends on area of forest, harvest age, and cutting cycle:

(54) Sequestered carbon: $A = F_2(FU, T, T^*)$.

Equations could also be added to indicate the amount of carbon released due to logging, fuelwood collection, and land degradation, but these amounts are exactly offset by the amounts sequestered due to reforestation and forest growth.

4.8 Macro Closure

The stylized model assumes no savings/investment terms and no government deficit. As noted in Section 4.5, household income is spent fully on consumption, while government revenue is spent fully on subsidizing the household and production sectors and purchasing reforested land. The current account can be balanced either by fixing the foreign exchange rate (R) and freeing the trade deficit (BOP), or vice versa.

4.9 Applying the Model

The proposed model includes numerous parameters that must be quantified before the model can be appled. Accurate estimation of these parameters is as important as specifying the model appropriately. Given that many developing countries have inadequate time-series data for econometric estimation of these parameters, there may be no choice but to apply the calibration approach. However, econometric estimation is preferred if data are available, even if for only a subset of the parameters. Moreover, creating a social accounting matrix (SAM) containing entries for deforestation and reforestation activities would help ensure that the data used to create the model are internally consistent.

The model contains numerous policy variables (tax rates, subsidies, harvest age, cutting cycle, etc.) that can be used to formulate policy scenarios. These scenarios predict the area of land in different categories, and the level and types of use of the forest (logging, fuelwood collection, production and consumption externalities), in a steady-state situation. That is, policy variables can be modified singly or in groups to generate predictions about the impacts on such variables as area of forest.

Following are some suggested scenarios:

(1) Trade policies:

- Log export restrictions: fix the amount of log exports, E_g, instead of treating it as endogenously determined by relative prices
- Export taxes on logs and wood products: adjust te_g, te_f
- Import restrictions in timber-importing countries: adjust world export prices for logs and wood products, PWE_g and PWE_f
- Exchange rate: fix the exchange rate, R, and let the trade balance (BOP) adjust

(2) Fiscal policies:

- Subsidies: adjust c_r (reforestation), c_a (permanent agriculture)
- Output taxes on logging and squatters: adjust tc_g and tc_q
- Property tax on agricultural land: adjust tp
- Output taxes on wood products: adjust tc_f

(3) Forestry policies:

- Harvest age of trees: adjust T
- Length of cutting cycle: adjust T^* (which must an integral divisor of T)
- Forest protection: adjust FU_{park}
- Stumpage tax: adjust ts
- Property rights: adjust δ_q, δ_g

Policies analogous to the ones listed above, but in sectors other than forestry, can also be simulated to investigate their impacts on forest area, forestry output, and carbon sequestration. In addition, the effects of improvements in agricultural productivity can be investigated by increasing the value of the a_{au} and a_{qu} parameters.

Appendix: Description of CGE Models Reviewed for the Study

Bergman, Lars. (1990). Energy and Environmental Constraints on Growth: A CGE Modeling Approach. Journal of Policy Modeling, 12(4):671-691.

Bergman, Lars. (1991). General Equilibrium Effects of Environmental Policy: A CGE-Modeling Approach. Environment and Resource Economics, 1(1):43-61.

Purpose of the Study

To quantitatively estimate the impact of environmental constraints on an economy. Specifically, to analyze the impact of air pollution emission control policies on sectoral economic growth, including the growth of forest industries. The model is applied to Sweden.

Brief Description of the Model

The model is a static, seven-sector, open-economy model with four types of intersectorally mobile production factors: capital, labor, electricity, and roundwood. It includes a sector (FOREST) aggregating forestry and the pulp and paper industries. FOREST produces tradable products and is a price-taker on the international market.

Different from standard CGE models, it includes pollution emissions and emission control activities, as well as markets and market prices for tradable emission permits. It is calibrated to a 1985 social accounting matrix and pollution emission data for Sweden. Growth during 1985-2000 is simulated under scenarios ‘with’ and ‘without’ constraints on air pollution emissions.

In his latest work, Bergman (1993) revises the model by taking into account the effects of environmental quality on both utility and production functions.

Policy Findings

When constraints on the emissions of SOx and NOx are imposed, there is a slight decrease in the output of the forestry industry. However, this negative impact is insignificant compared to the decrease that occurs in the steel and chemical industries.

Comments

Linkages between forest industries and the forest are not defined, as the model does not include forest land as a production factor. Instead, the supply of roundwood is exogenously given. Consequently, the model is incapable of capturing the effects of environmental policies on forest land and the supply of roundwood.

Coxhead, Ian and S. Jayasuriya. (1994). Technical Change in Agriculture and Land Degradation in Developing Countries: A General Equilibrium Analysis. Land Economics. 70(1):20-37.

Coxhead, Ian and G. Shively. (1995). Measuring the Environmental Impacts of Economic Changes: the Case of land Degradation in Philippine Agriculture. University of Wisconsin-Madison, Staff Paper Series No. 384.

Bandara, J.S. and I. Coxhead. (1995). Economic Reforms and the Environment in Sri Lanka. Agricultural Economics Discussion Paper 27/95, La Trobe University, Victoria, Australia.

Purpose of the Study

To analyze the role of economic linkages among upland agriculture, lowland agriculture, and other sectors in developing economies, and the potential for welfare-enhancing shifts toward less erosive upland land-use patterns.

Brief Description of the Model

The model in Coxhead and Jayasuriya (1994) is an analytical general equilibrium model. It assumes a simplified two-region (upland and lowland), three-sector (food crop, tree crop, and manufacturing) economy. The upland region produces tree crops and food, while food and industrial products are produced in lowland areas. Tree crops are mainly for export. Production factors in the model are labor, capital, and land. The two regions are linked by both output (food) and input (labor) markets.

The focus of the model is the potential impact of technical progress on land-use patterns, especially land allocation for tree crops and food crops in the upland region, as well as soil erosion related to the increase of food production in that region. The model assumes that technical progress increases the effective quantities of factors and reduces their effective prices.

Policy Findings

Technical progress in lowland agriculture reduces upland agricultural activities and alleviates upland land degradation (mainly deforestation and soil erosion). Technical progress in production of tree crops does not, however, necessarily reduce upland food cultivation, which is the main driver for deforestation. Indeed, it may cause upland food crop area to expand. Policies aimed at slowing land degradation through technical progress in upland crops might therefore have the opposite of their intended effects.

Comments

The effects of technical progress and macro policies on deforestation are indirectly indicated through changes in land allocation for tree crops and food in the uplands. Forest and agricultural lands are assumed to be instantly interchangeable. Negative environmental impacts from deforestation do not feed into production of agriculture or other sectors.

Bandara and Coxhead (1995) and Coxhead and Shively (1995) apply the model to Sri Lanka and the Philippines, respectively.

Cruz, Wilfrido and R. Repetto. (1992). The Environmental Effects of Stabilization and Structural Adjustment Programs: the Philippines Case. World Resources Institute.

Purpose of the Study

To examine the environmental effects of stabilization and structural adjustment programs in the Philippines. Effects on forests are determined implicitly, through changes in logging activity.

Brief Description of the Model

The model is a standard CGE model, following in the tradition of Shoven and Whalley's modeling framework for taxation policy. It includes 14 production sectors, among which there is a forestry sector (logging) that causes deforestation. Land is included as a production factor for the agriculture and forestry sectors, along with labor and capital. Three household categories, classified by income, are identified in the model.

Policy Findings

Trade liberalization increases logging activity and, as a consequence, is assumed to promote deforestation. Industrial subsidies contribute little to industrial growth, but they generate negative impacts on the environment, including deforestation.

Comments

The model does not analyze deforestation in-depth; it simply assumes that deforestation is proportional to logging. Land is apparently not carefully distinguished by its use for agriculture and for the logging industry, although this is difficult to determine because a detailed description of the model is not available.

Dee, Philippa S. (1991). The Economic Consequences of Saving Indonesia's Forests. National Centre for Development Studies, The Australian National University, Working Paper No. 91/7.

Dee, Philippa S. (1991). Modeling Steady-State Forestry in a Computable General Equilibrium Context. National Centre for Development Studies, The Australian National University, Working Paper No. 91/8.

Purpose of the Study

To examine how to enforce a forest protection policy, and to identify the distributional implications of such a policy in Indonesia.

Brief Description of the Model

The model is in the line of the ORANI model (see Dixon et al. 1982). It includes agriculture, minerals, and forestry, all of which are land using, along with agricultural processing, mineral processing, wood processing, manufacturing, and services. The nonforest sectors are represented by conventional, single-period production functions, but the forest sector is represented by a steady-state solution to the intertemporal harvesting problem.

The model includes factor demands for labor, capital, land, and material inputs by a single representative consumer, the government, industries, and foreigners. These demands are consistent with cost minimization, subject to constant returns-to-scale technology.

Two alternative treatments of land mobility are assumed. In the first, land use in all industries is held fixed. In the second, land is mobile between agriculture and forestry, and it moves towards the use in which its discounted returns are greater.

Policy Findings

The impact of forest protection policies depends on the flexibility of land-use patterns. When land is mobile between agriculture and forestry, removing assistance to agriculture and industry increases the volume of standing timber. The burden of a decrease in real GDP caused by forest protection needs not fall on the rural poor if, among other things, land is mobile.

Comments

The modeling of the forest sector is unique. The shift from forest land to agricultural land is assumed to be instantly reversible, however; no time delays are considered. Because the model includes only one representative household, conclusions regarding the distributional effects of forest protection are questionable.

Development Strategy Institute and HIID. (1995). Structural Adjustment, the Environment, and Sustainable Development in Vietnam. Summary Report to World Wildlife Fund.

Purpose of the Study

To test macroeconomic policy alternatives, including subsidies for reforestation, for their impacts on sustainability.

Brief Description of the Model

The paper contains only limited information on the model. The model has 45 sectors, and it explicitly models the production impacts of environmental externalities. It permits users to obtain the social cost of alternative policies, with environmental features included, in terms of a money-metric social welfare gain or loss.

The model assumes that there is 1.4 hectares of deforestation for every hectare of additional land brought under agricultural production. It also includes a deforestation/erosion relationship.

Policy Findings

Subsidizing reforestation through a logging tax or a surcharge on energy prices causes economic losses in the sectors taxed. However, it produces remarkable gains in employment and national income. Both scenarios indicate that deepening the natural capital base, through reinvesting gains from resource use, generates growth today and secures it for future periods.

Comments

Due to the limited information available, it is unclear how environmental and forestry components are endogenized in the model. It appears to be through a fixed-coefficients approach.

Dufournaud, Christian M., J.T. Quinn, and J.J. Harrington, (1992). Energy Policy Analysis in a Computable General Equilibrium (CGE) Model: the Case of the Sudan. Unpublished paper.

Purpose of the Study

To evaluate the impacts of alternative energy policies (specifically, the introduction of more efficient wood stoves) on the clearcutting of scrub for firewood in Sudan.

Brief Description of the Model

The model is a standard CGE model for a small open economy. It follows closely the framework pioneered by Dervis et al (1982). It contains seven production sectors plus a 'domestic work' sector. It is calibrated to the 1984 social accounting matrix for the Sudan.

The model distinguishes between gathered and purchased wood. Gathered wood is supplied by the 'domestic work' sector, and it is used by households only. Its supply is modeled using a linear production function, assuming that households cannot realize economies of scale in gathering wood.

Policy Findings

Increasing the efficiency of wood stoves is not a successful policy for curtailing the clearcutting of scrubland. Due to a 'rebound effect,' the introduction of more efficient stoves increases household consumption of wood and, as a consequence, adds pressure to the country's woodlands.

Comments

The quantity and quality of forest land are not explicitly modeled. The impact of policies on woodland is therefore only indirectly inferred.

Girma, Messaye (1992). Macropolicy and the Environment: A Framework for Analysis. World Development. 20(4):531-540.

Purpose of the Study

To create a stylized general equilibrium model that shows how natural resource services may be incorporated as a sector of the macroeconomy by including markets for them.

Brief Description of the Model

In the line of classical stylized CGE models, the author models a simplified closed economy with only households and firms endogenously incorporated. In contrast to standard CGE models, however, the model includes natural resources as a source of services as well as goods. Natural resource services appear in the production functions for non-resource sectors and in the demand functions of consumers. Public environmental goods like clean air are, however, excluded from the model.

Policy Findings

Aggregate demand policy, sectoral policy, and distributional issues are examined graphically. Impacts of the policies are discussed in general terms, without a focus on forests.

Comments

The study only attempts to demonstrate a way to incorporate natural resource services into a simple, stylized CGE model. Public environmental goods are ignored.

Harrigan, Frank. (1992). The Economic Costs of an Abatement of Tropical Logging: An Applied General Equilibrium Analysis of the Malaysian Case. Unpublished paper.

Purpose of the Study

To measure the potential costs of an abatement of tropical logging to the Malaysian economy.

Brief Description of the Model

The model, called M4, is an applied CGE model of the Malaysian economy. It includes thirteen sectors, one of which is a forestry sector with logging activities. The model is designed to analyze long-run structural changes in the economy. The simulation period is 1983 to 2050.

Most of the behavioral relationships are derived from static optimizing behavior, but the model is specified in a steady state formulation. The flow of output from the forestry sector is assumed to be exogenous. The impact of reducing logging activity can therefore be observed by comparing economic output with and without this output.

Policy Findings

Reducing logging decreases GDP, government tax revenue, and consumption. The costs are surprisingly large, given the initial modest contribution by the logging sector to GDP. The explanation is that the domestic economy must permanently forgo consumption to enable it to service the higher level of net foreign indebtedness that follows from the loss of logging export revenue and, to a lesser extent, because the public sector must raise tax revenue to ensure its ‘solvency’ following the loss of commodity taxes on forestry.

Consequently, compensation might have to be paid to a small open economy like Malaysia to secure its agreement to an abatement of tropical logging activity.

Comments

The model is essentially a static model, even though it is used for simulating the path of the Malaysian economy over time. The steady-state condition and many other assumptions regarding timepaths of variables (e.g., that output of the forest sector is exogenous) weaken the relevance of the finding.

The model does not attempt to quantify the benefits of preserving Malaysian tropical forests.

Panayotou, Theodore and C. Sussangkarn. (1991). The Debt Crisis, Structural Adjustment and the Environment: the Case of Thailand. Prepared for WWFN's project on the Impact of Macroeconomics Adjustment on the Environment.

London Environmental Economics Centre. (1992). Structural Adjustment and the Environment: Case Study for Thailand. In D. Reed, ed., Structural Adjustment and the Environment. Boulder: Westview Press.

Purpose of the Study

To identify and analyze the implications of structural adjustment and related macroeconomic policies on the natural resource base and the ambient environment of Thailand. Among other environmental implications, the impacts of structural adjustment on forests are examined.

Brief Description of the Model

The model is a standard CGE model, with 90 production sectors (including forestry and wood processing) and 3 production factors (land, labor, and capital). Land is separated into two types: land used for logging and land used in agriculture. The quantity of land used for logging is fixed, however. Land used for agricultural activities is endogenously determined as a function of agricultural value-added and agricultural employment. The model is calibrated to a 1982/84 SAM for Thailand.

To estimate the environmental impacts of macropolicies, a set of fixed environmental parameters is assumed. For example, it is assumed that expansion of agricultural land results in a 1.4 times larger area of land deforested.

Policy Findings

Five simulations are conducted. The main forest-related implications can be summarized as follows:

> --A reduction in the export tax on rice (or rubber) switches land from upland crops to rice (or rubber) and exacerbates deforestation.

--An increase in the export of labor-intensive manufactured products attracts labor out of agriculture and may reduce forest encroachment, deforestation, and soil erosion.
--A reduction in real public-sector investment leads to a drop in domestic prices and boosts the agricultural sector, resulting in additional forest encroachment.

The authors observe that poverty is a major cause of deforestation and that economic growth that alleviates poverty will benefit forest resources.

Comments

As the authors acknowledge, the environment is not integrated with the economy in the model: "No attempt is made to feed back the environmental impacts into the simulation model to obtain their effect on the economy." Because land used for logging is fixed, while the demand for agricultural land is determined endogenously, no overall constraint on land resources is included in the model.

Persson, Annika and M. Munasinghe. (1995). Natural Resource Management and Economywide Policies in Costa Rica: A Computable General Equilibrium (CGE) Modeling Approach. The World Bank Economic Review. 9(2):259-285.

Purpose of the Study

To trace the effects of government policies on Costa Rican forests in the presence of incomplete markets.

Brief Description of the Model

The model is a static, small open-economy model with seven sectors. Among the sectors are forestry (wood processing), agriculture, and two deforestation sectors: logging and squatter agriculture. Mobile production factors included in the model are unskilled labor, skilled labor, capital, logs, and cleared land. Logs and cleared land are specific to forestry and agriculture, respectively. Both loggers and squatters demand unskilled labor, but only loggers use capital.

The production structure of the model is fairly typical of CGE models. It differs in two important respects, however. First, it takes into account the effects of property rights in two different scenarios: undefined and well-defined property rights. Second, it includes markets for logs and cleared land. Logs are harvested by the logging sector and sold to the forestry sector. Cleared land is supplied by squatters only and is used by the agriculture sector.

The model is calibrated to the 1986 input/output table of Costa Rica.

Policy Findings

According to Munasinghe and Cruz (1995) "The results of the simulations support the conventional view that establishing property rights tends to decrease deforestation. The reason is that such rights allow the logging sector to capture the future benefits of reducing excessive logging damage on residual stands." Other findings include:

> --Higher interest rates promote deforestation, while lower interest rates promote conservation.
> --An increase in stumpage fees reduces logging. However, while deforestation from logging decreases, total deforestation increases. This is because the contraction of the logging and forest industry sectors causes a shift of resources toward agriculture and, as a result, increases demand for cleared land.
> --Lowering the tax on unskilled labor reduces deforestation because people gain employment in other parts of the economy.
> --Lowering the tax on agricultural products reduces agricultural output, and deforestation, due to expansion of the industry sector.

Comments

The constraint of forest land on forestry, deforestation, and agriculture is ignored in the model because the amount of land available for deforestation is assumed to be unlimited. The assumption of independence between the logging and squatter sectors might also pose problems, since both sectors share the same resource, i.e., forest land.

Persson, Annika. (1995). A Dynamic CGE Model of Deforestation in Costa Rica. in C.A. Perrings et al. (eds.), Biodiversity Conservation, Klewer Academic Publishers. 215-235.

Purpose of the Study

To investigate the impacts of market failures and macro policies on deforestation in Costa Rica using an intertemporal CGE model.

Brief Description of the Model

The model is a two-period intertemporal CGE model with endogenous savings and investment. It is an intertemporal extension of the static CGE model developed by Persson and Munasingle (1995).

When property rights are undefined, the squatter or logging company ‘owns’ forest land for only one period and have no incentive to practice forest conservation. In that case, the production behavior of a squatter or logging company is the same as in a static model. When property rights are well defined, the squatter and the logging company own the land in both periods. They therefore face an intertemporal maximization problem and make allocation decisions by maximizing the present value of utility in both periods, subject to an intertemporal budget constraint.

In addition to the above modifications a limit on the amount of land available for deforestation is included in the model, and this constrains the outputs of both squatters and the logging sector.

The intertemporal model is calibrated to the 1986 social accounting matrix of Costa Rica.

Policy Findings

A reduction in the amount of allowable deforestation decreases utility in the first period. The prices of both land and capital rise, causing to agricultural production to decrease and industrial production to increase.

An intertemporal tax on capital imposed in period 0 increases squatting and logging activities in that period due to relative price changes. An increased tax on capital in period 1 does not, however, affect production and consumption decisions in period 0.

A temporary land subsidy in period 0 actually decreases deforestation in that period, rather than increases it as expected. Relative price changes that spill over to the rest of the economy and affect investment behavior play an important role.

Thiele, R. and M. Wiebelt. (1993). National and International Policies for Tropical Rain Forest Conservation - A Quantitative Analysis for Cameroon. Environmental and Resource Economics. 3:501-531.

Thiele, R. (1995). Conserving Tropical Rain Forests in Indonesia: A Quantitative Assessment of Alternative Policies. 46(2):187-200.

Purpose of the Study

To investigate the effects of a set of macro policies that combine the removal of domestic distortions, national environmental policy measures, and international measures, and to sort out policy packages that simultaneously protect tropical forests and stimulate efficient resource allocation.

Brief Description of the Model

The model in Thiele and Wiebelt (1993) is a standard CGE model extended by including a forestry submodel. The economic part of the model follows conventional procedures as described in Dervis et al. (1982). Along the lines of Dee (1991), forestry production is derived from an intertemporal harvesting problem in which the optimal harvest age is determined by maximizing the present value of net returns from current and future harvests, at given timber prices, harvesting costs, interest rates, physical growth characteristics of trees, and a minimum harvest age of trees. Annual timber output, therefore, is a steady-state solution and is defined as a function of forest land divided by the rotation period times the harvest volume per hectare per rotation. The demands of the forestry sector for non-land inputs (capital, labor, and intermediate inputs) are assumed to be fixed per rotation. Agricultural land and forest land are distinguished from each other, but they are assumed to be instantly exchangeable. The supplies of production factors (including agricultural land and forest land) are exogenously fixed.

Policy Findings

The study simulates a variety of policy alternatives which broadly reflect the continuum of national and international policies currently suggested in the environmental and resource economics literature. These policy alternatives can be divided into three groups: forest management policies, trade policies, and international measures. The major simulation results are summarized as follows.

The first group includes four different policies. They are: an increase in the length of forest leases, an increase in the stipulated minimum harvest age of trees, a direct set-aside in the form of national parks, and a tax on income from forest land. All induce a considerable reduction of forestry's production and exports, forcing domestic producer prices upward. The direct set-aside and tax policies reduce demand for forest land significantly.

Reductions in import tariffs and export taxes on agricultural goods reallocate land from forest to cash crops, and, as a consequence, speed up the pace of deforestation. However, a general abolition of import tariffs pushes up the price of timber because the forestry sector has a very low supply elasticity. The steep timber price increase attracts land to the forestry sector and reduces the pace of deforestation.

An import ban on Cameroon's logs and processed timber reduces forestry production, but it causes a reallocation of forest land from forestry to cash crops. It also causes a decline in real GDP. So, such import restrictions are ecologically ineffective and place considerable costs on the economy.

The provision of additional financial resources from the international community is necessary for Cameroon to ensure a higher level of protection of tropical rain forests.

Comments

Both agricultural and forest lands move freely across sectors toward the use in which discounted returns to land are greater. The assumption that the switch between agricultural land and forest land is instant is, of course, not true, and it is not clear how land resources are constrained. The model ignores reforestation activities.

The same type of CGE model has been applied to a case study of Indonesia in the second paper. The results of most policy simulations are identical.

Table 2-1. List of Major Policy Findings Related to Deforestation

A. Policies Exacerbating Deforestation

(i) Trade policies:
- Trade liberalization, due to increased logging activity (Cruz and Repetto 1992, Philippines)
- Reducing import tariffs and export taxes on agricultural goods (Thiele and Wiebelt 1993, Cameroon)
- Reducing export taxes on upland crops (Panayotou and Sussangkarn 1991, Thailand)
- Timber import bans or restrictions by trading partners (Thiele and Wiebelt 1993, Cameroon)

(ii) Fiscal policies:
- Raising taxes on capital (Persson 1995, Costa Rica)
- Industrial subsidies (Cruz and Repetto 1992, Philippines)
- Reducing real public sector investment (Panayotou and Sussangkarn 1991, Thailand)

(iii) Forestry policies
- Increasing stumpage fees (reduces logging, but increases deforestation due to an increased demand by agriculture for cleared land; Persson and Munasinghe 1995, Costa Rica, and Thiele and Wiebelt, Cameroon)
- Proclaiming protected areas (Thiele and Wiebelt 1993, Cameroon)

(iv) Other policies/factors
- Raising interest rates (Persson and Munasinghe 1995, Costa Rica)
- Technical progress in production of tree crops (Coxhead and Jayasuriya 1994)
- Increasing the efficiency of wood stoves (due to indirect effects; Dufournaud et al. 1992, Sudan)

(Continued on next page)

Table 2-1 (continued)

B. Policies Reducing Deforestation

(i) Trade policies

- Abolishing import tariffs on all goods (due to income effect pushing up the price of timber; Thiele and Wiebelt 1993, Cameroon)
- Reducing export tax on labor-intensive manufactured goods (Panayotou and Sussangkarn 1991, Thailand)

(ii) Fiscal policies

- Lowering taxes on unskilled labor (Persson and Munasinghe 1995, Costa Rica)
- Lowering taxes on agricultural products (due to indirect effects; Persson and Munasinghe 1995, Costa Rica)
- Temporary land subsidies (Persson 1995, Costa Rica)
- Removing subsidies to agriculture and industry (Dee 1991, Indonesia)

(iii) Forest policies

- Establishing property rights (Persson and Munasinghe 1995, Costa Rica)

(iv) Other policies/factors

- Technical progress in lowland agriculture (Coxhead and Jayasuriya 1994)
- Raising energy prices (Cruz and Repetto 1992, Philippines)
- Additional financial resources from the international community (Thiele and Wiebelt 1993, Cameroon)

Table 4-1. Production Sectors and Factor Inputs

Sector	Name	Inputs	Abbreviation
1	Permanent agriculture	L,K,AE,AU	a
2	Manufacturing	L,K,AE	m
3	Low CO2 energy	L,K,AE	eh
4	High CO2 energy	L,K,AE	el
5	Fuelwood collection	L,FU	fw
6	Wood processing	L,K,AE,G	f
7	Logging	L,K,AE,FU	g
8	Squatter agriculture	L,QU	q
9	Reforestation	L,K,AE,DU	r

Figure 4-1: Structure of the Model

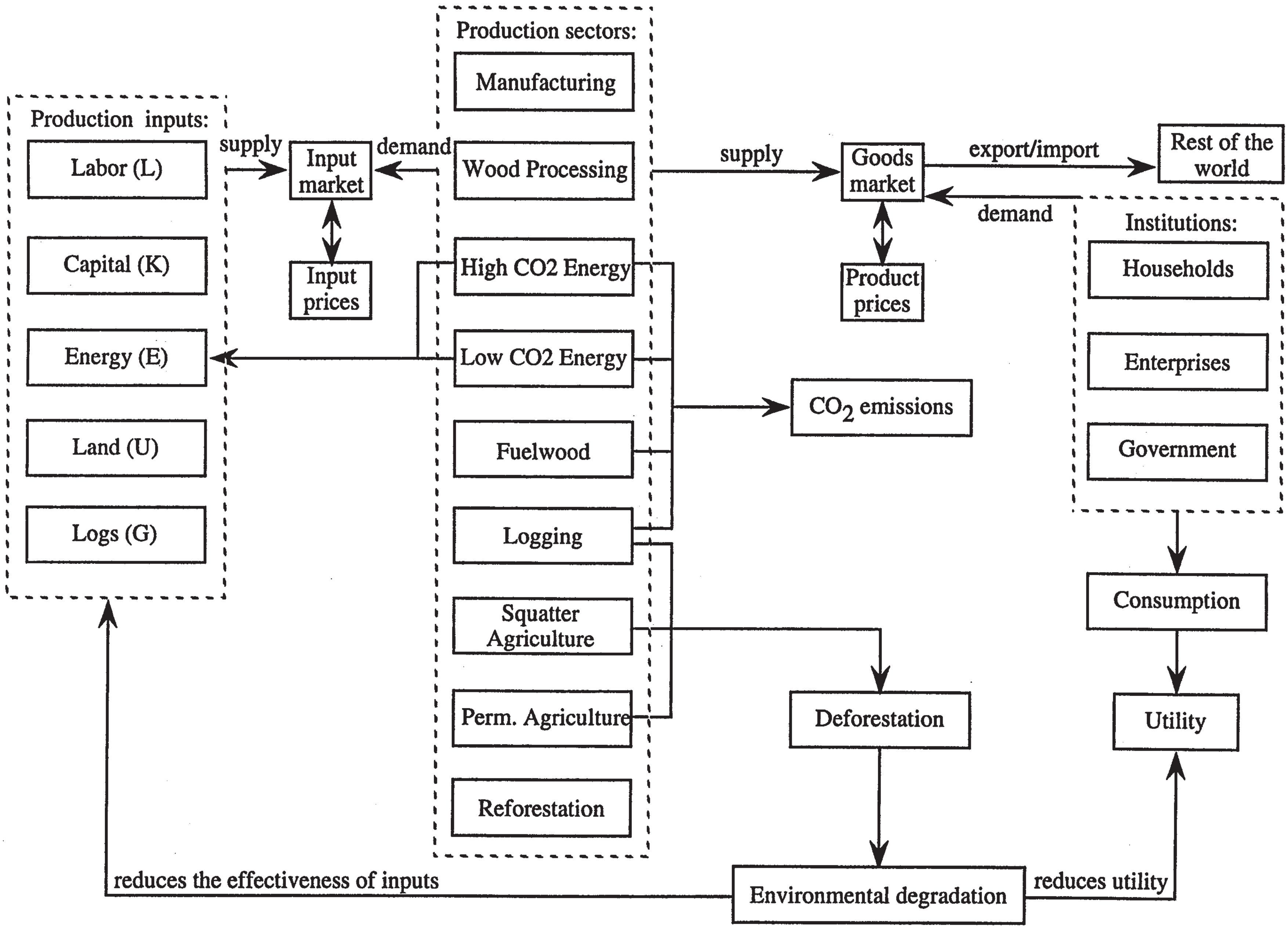
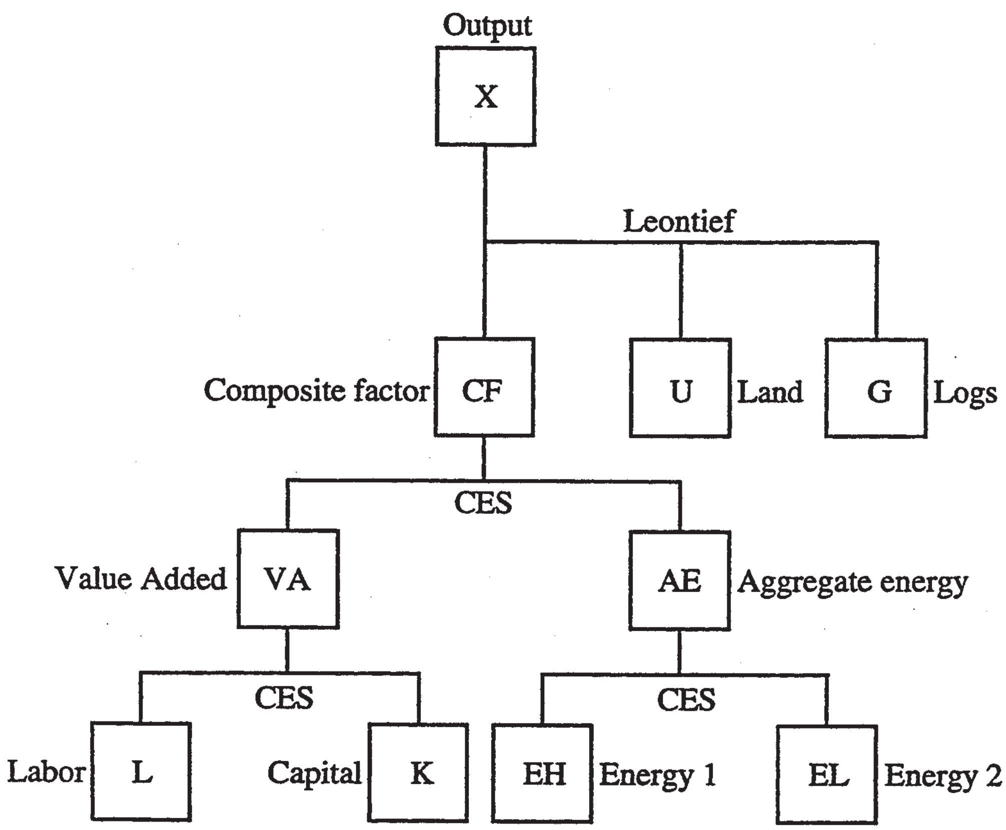


Figure 4-2: Production Structure



Energy 1: high CO_2 emission energy
Energy 2: low CO_2 emission energy

Figure 4-3: Forest Harvesting

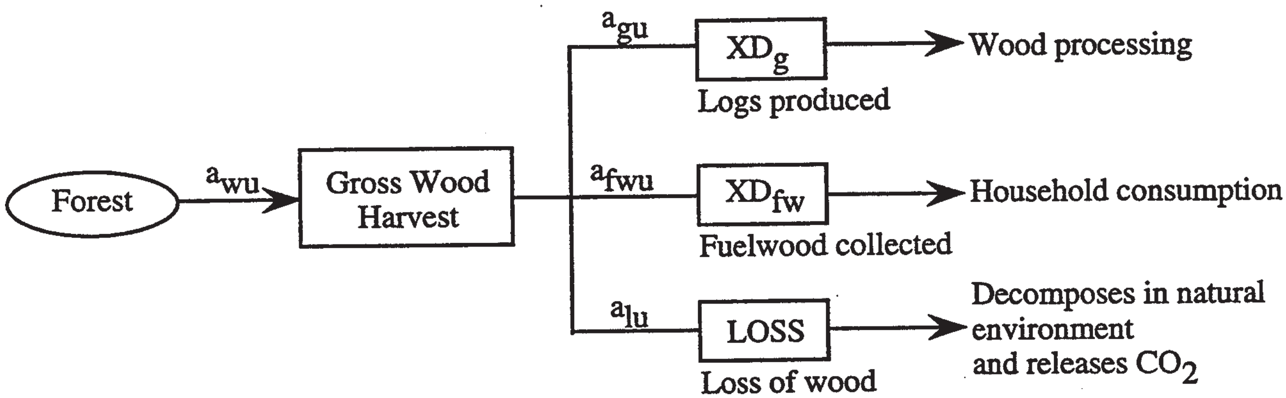


Figure 4-4: Supply and Demand of Goods

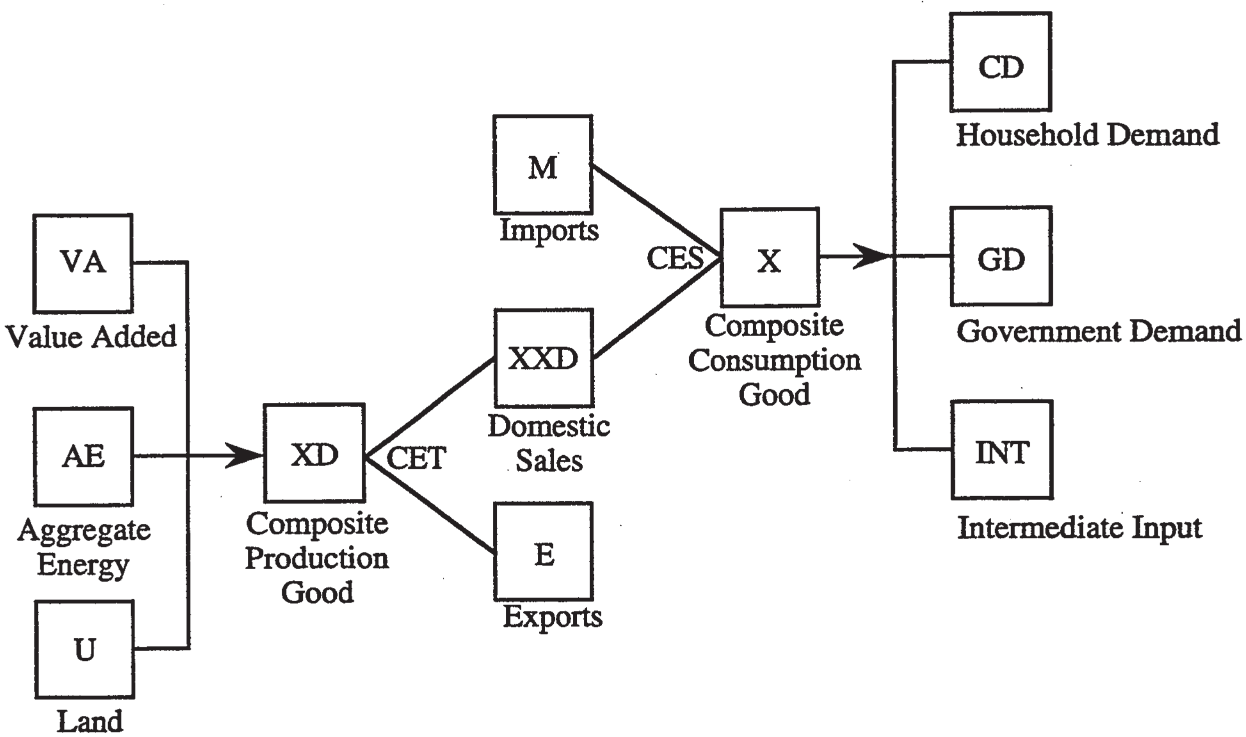


Figure 4-5: Relationships Among Prices

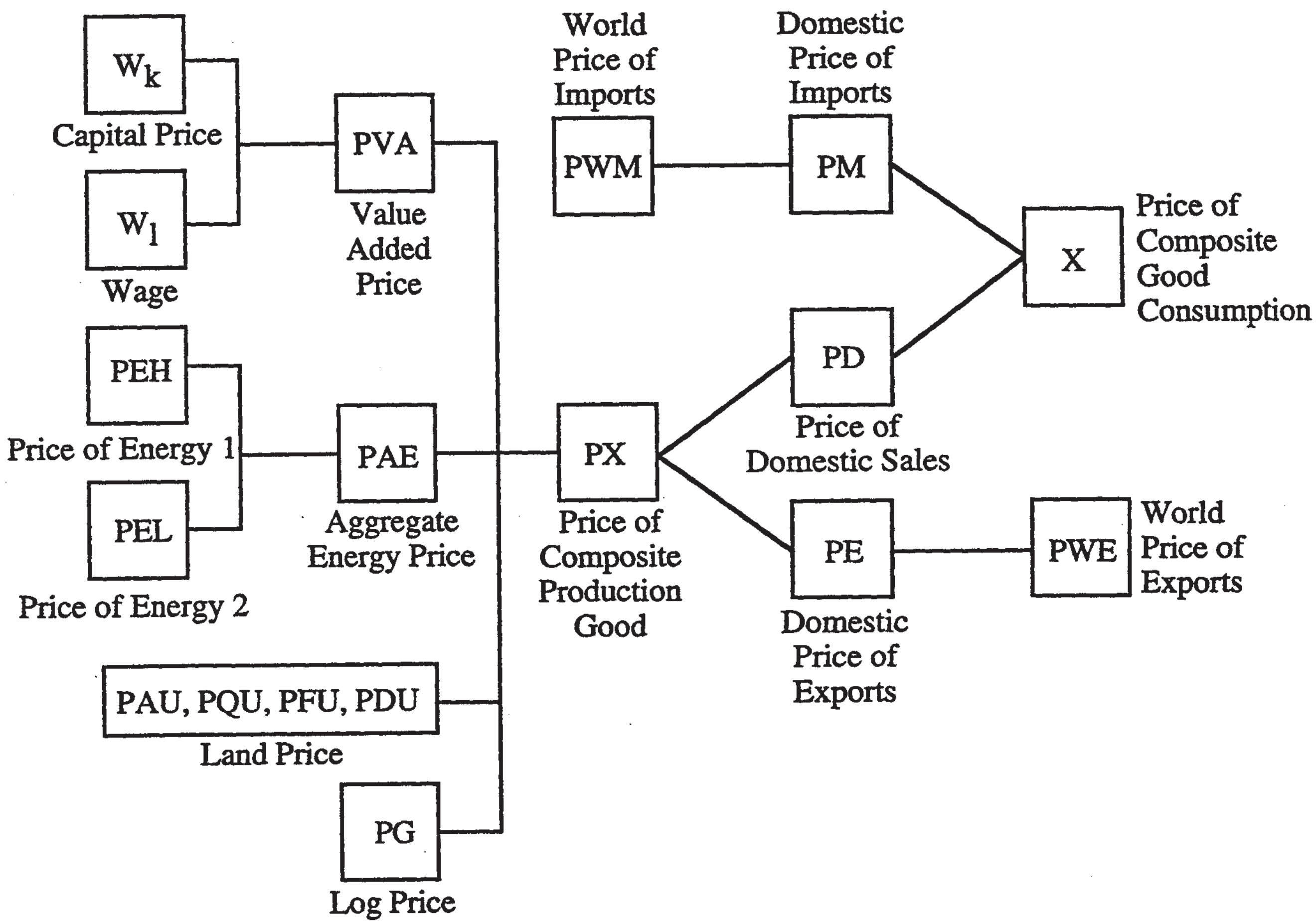
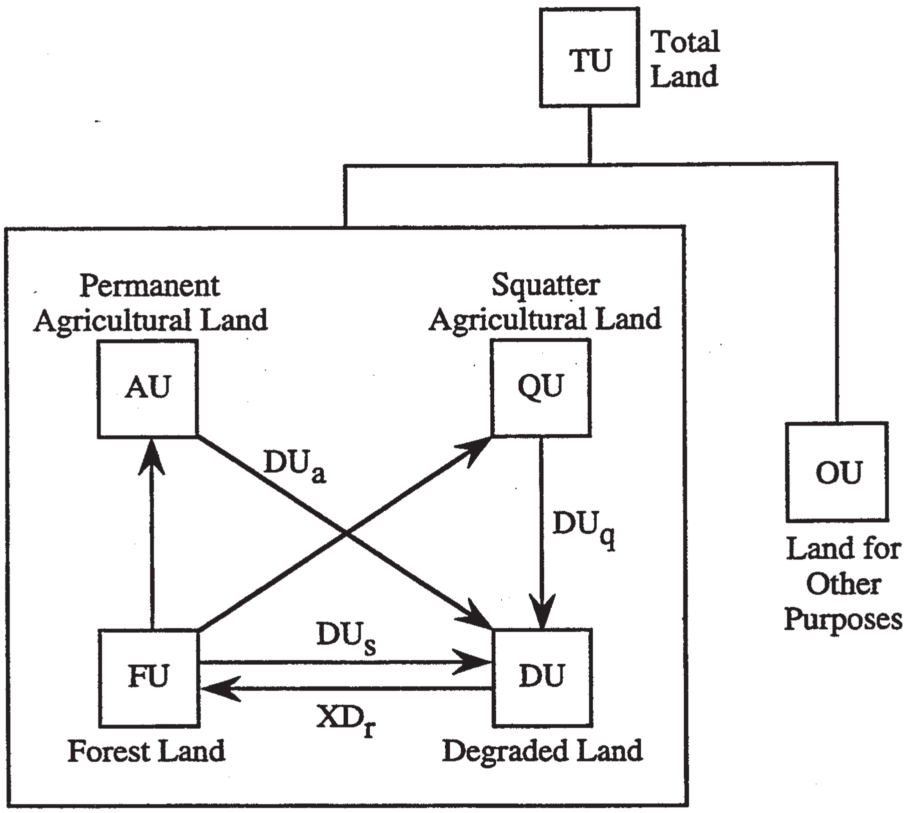


Figure 4-6: Relationships Among Land



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