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1. Introduction

Tropical deforestation continues to be one of the major isues discussed at international conferences on global environmental problems (e.g. conferences on global climate in Geneva 1990 and in Brazil 1992). Though tropical deforestation incurs severe global and local environmental problems, effective international and national policy measures and actions have not been implemented yet, partly because there is a lack of policy conceptions.

Recent studies on deforestation in tropical rain forests (e.g. Amelung, Diehl (1991), EK (1990), Brünig (1989), Oberndörfer (1988), Oberndörfer (1989), World Resource Institute (1985)) came up with two main policy conclusions:

- As there are a number of sectors involved in tropical deforestation, i.e. mining and related industries, forestry, agriculture as well as hydroelectricity production, the key to conservation of tropical forests consists of a bundle of policy measures. This policy package has to aim both at the agricultural sector and the forestry sector which successively or jointly use rain forest resources and are the major causes of tropical deforestation.

- Deforestation in the tropics incurs negative externalities for industrial countries, e.g. the extinction of biological species and the aggravation of the greenhouse effect (Houghton et. al. (1990), Myers (1989), EK (1990)). In order to internalize these international externalities domestic policy measures in tropical countries have to be complemented by international or multilateral policy measures, e.g. trade barriers against all products produced by using tropical forest resources or compensation payments for countries willing to protect sizeable rain forest areas (Ruitenbeek (1990), Amelung (1989), Oberndörfer (1989)).[1] In theory, both of these policy measures can internalize international externalities under certain assumptions.

Recent studies of various policy measures aiming at the conservation of tropical rain forests, e.g. long-term logging concessions, resource use taxes, proper land titling, agricultural taxation in tropical forest areas, export taxes, import barriers for tropical hardwood etc. (Oberndörfer (1989), Amelung (1989), Ruitenbeek (1990), EK (1990), Pearce, Barbier, Markandya (1990)) have been quite tentative in nature. There are mainly two reasons for that. Firstly, most of these studies have been confined to the analysis of one specific market, cash crops produced in tropical forests, tropical hardwood, or one specific sector, e.g. forestry or agriculture.[2] Since there are a number of economic sectors involved in the exploitation of tropical forest resources, a partial analysis of particular sectors and markets cannot be considered as a well-suited framework for economic

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1 Global concerns with respect to tropical deforestation cannot be simply traced back to the fact that it leads to an irreversible destruction of an unique ecosystem. On top of that, it has been proven that tropical deforestation adds to the greenhouse effect (Crutzen et al. (1989), Houghton et al. (1987), Hall et al. (1990)), since the burning and decay of biomass in tropical rain forests causes emissions of CO, CO_2, CH_4 and NO_x, which, together, have been termed as "greenhouse gases". Following Myers (1989a,b), 30 percent of global CO_2 emissions in 1989 were due to tropical deforestation. Since the biomass in tropical rain forests can be considered as reservoir binding CO_2, a reduction of clearing in tropical forest areas could substantially reduce the emission of greenhouse gases. Moreover, rain forests feature a variety of unknown biological species which have been utilized as a research input for the pharmaceutical sector and the producers of agricultural inputs. Hence, the extinction of ecological species and the emission of greenhouse gases incur international externalities.

2 The tropical countries regard their tropical forest resources as an input for their economic development (Steinlin (1989) Pretzsch (1989)). Tropical rain forests do not only provide wood which is a major input for domestic wood and construction industries. Even more important are the land reserves covered with tropical rain forests which are utilized for agricultural expansion. Moreover, tropical forest areas bear a high hydroelectric potential and mineral reserves that form a base for the development of the mining sector and related industries.

analysis, since this approach does not take into account the interdependence between economic sectors and between subsectors.

Secondly, it has to be taken into account that economic policies aiming at the protection of tropical forests are implemented in a policy regime that discriminates among economic activities. In most tropical countries governments tend to favour particular sectors, mainly capital-intensive manufacturing or subsectors, e.g. food crops versus export crops in the agricultural sector (Amelung, Diehl (1991), Chap. 3, 4, Wiebelt (1990a), Wiebelt (1990b)). An appropriate economic analysis has to consider these policy distortions and their possible alteration. Such an approach cancels out partial analysis, which neglects sectoral interdependencies.

Thirdly, some international policy measures such as compensation payments or international allocations of carbon dioxide emission quotas do not impact on one single sector but on the entire economy of a tropical country. Compensation payments of industrial countries to tropical countries can be used in numerous ways in order to protect tropical rain forests. In order to compare the effects of such compensatory finance approaches a more comprehensive economic assessment is needed.

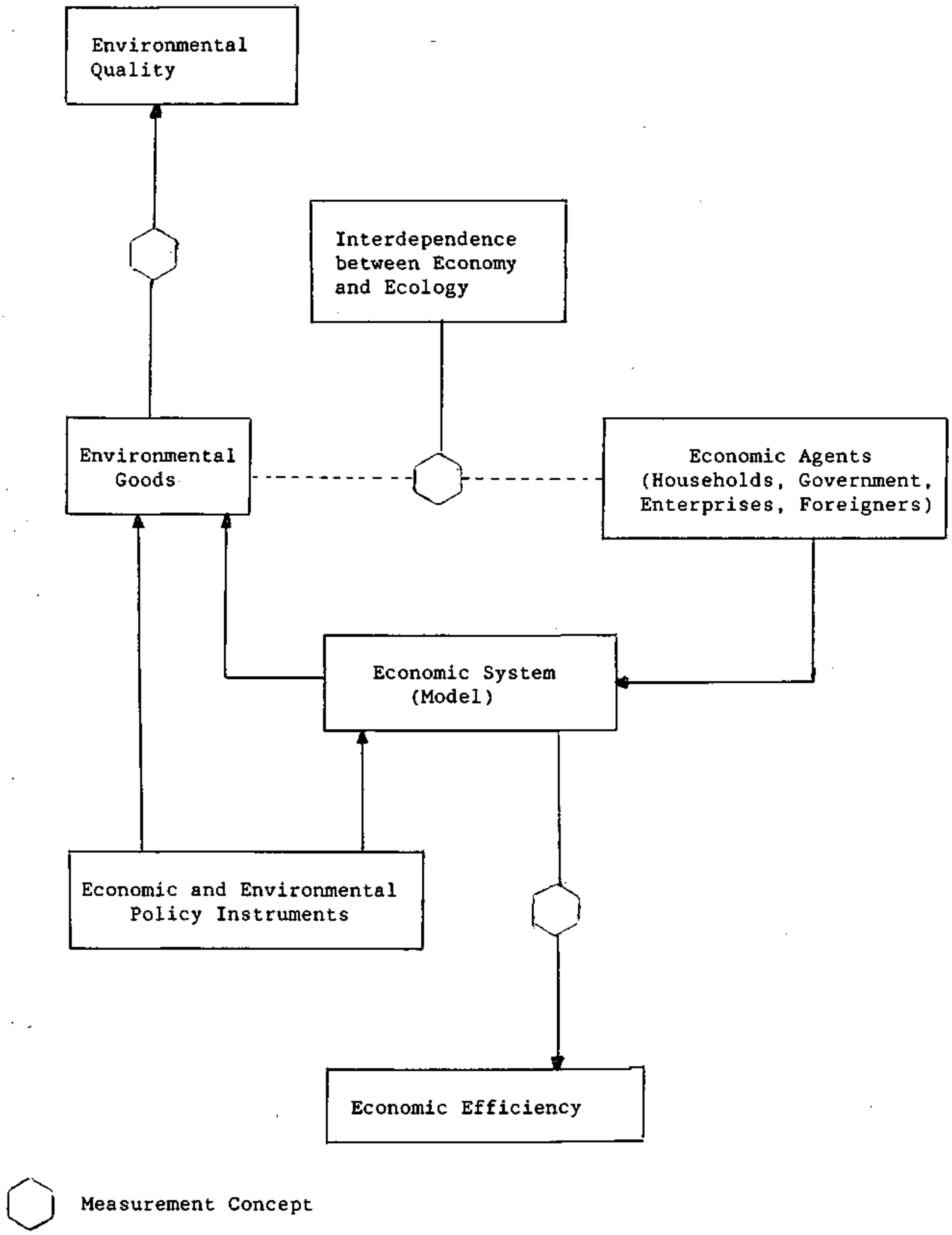
This paper is meant to briefly sketch the analytical tools that are available to evaluate the economic impacts of the various policy measures aiming at rain forest protection. The next Section gives an overview of the issues involved. Thereafter, in Section 3 input-output analysis is introduced as one possible tool of analysis. In Section 4 social accounting matrices are discussed, which are basically an extension of the input-output modells. Finally, in Section 5, computable general equilibrium models will be extended to include both ecological and economic effects.

2. The Interrelatedness of Ecological and Economic Systems in Economic Analysis

The previous section has shown, that the depletion of the rain forest ecosystem can be traced back to the exploitation of rain forest resources by various economic activities. Hence, for any economic analysis of deforestation it is first necessary to identify environmental goods and economic agents and to clarify their relationship (Pearce, Turner (1990), pp. 29-33). This is illustrated in Figure 1. Economic agents (households, government, enterprises and foreigners) engage in production, consumption, accumulation and trade of economic goods (the economic system) thereby consuming and producing environmental goods. The effects of these economic activities on environmental goods constitute the interdependence between economy and ecology. For a proper analysis of this relationship, it is advisable to distinguish between primary effects (impact multipliers) resulting from individual economic activities and final effects as a result of economic adjustment processes. As shown in Figure 1, the government can influence the consumption and production of environmental goods via economic and environmental policy instruments. The latter can affect the ecological system either directly by restricting the supply of environmental goods or indirectly via the economic system (e.g. taxes, subsidies etc.)

Finally, following Frey (1980) policies should be evaluated both in terms of economic efficiency and ecological effectiveness (Figure 1). The measurement of the latter criterion requires an indicator for environmental quality. A possible indicator for the consumption of rain forest resources is the depreciation of the natural assets of a country, as it was developed by Repetto et al. (1989). Moreover, a number of international institutions have been developing concepts for environmental accounting, e.g. the World Resource Institute (see Repetto et al. (1989)), the United Nations Environmental Programme (see Ahmad et al. (1989)) as well as a number of other research institutions (see Ryll/Schäfer (1988)). These approaches are capable to weigh the welfare loss

Figure 1


Environmental Quality
Interdependence between Economy and Ecology
Environmental Goods
Economic Agents (Households, Government, Enterprises, Foreigners)
Economic System (Model)
Economic and Environmental Policy Instruments
Economic Efficiency
Measurement Concept

due to declining environmental quality against welfare improvements from economic efficiency gains. However, such a normative analysis is not the objective of this paper. Instead, we will concentrate on positive analysis of the effects of economic activities and policy interventions on economic and environmental variables. Among others, input-output-analysis can be used to measure such effects.

3. Ecological Input-Output Models

Ecological input-output models are based on an extended Input-Output table (IOT) which also includes environmental goods in the material balances (Gehrig (1980, 1986)). Production and consumption are considered as processes which withdraw environmental "inputs" (natural resources) from the environment and release environmental "outputs" (waste) into the environment. The material balances constituting an ecological IOT can be formulated as follows:

(1) $A^S = F + N^S$

or

(2) $F + A^D = N^D$

where A^S (A^D) denotes the raw materials or natural resources used in connection with production (final demand), while N^S (N^D) is the waste due to production (final demand). F is the final demand (private and government consumption, gross investment, exports) including imports. Equations (1) and (2) can be combined to yield:

(3) $A^S + A^D = N^S + N^D$

Hence, given constant stocks of consumer goods, the ecological inputs used in production and final demand equal the ecological outputs of these activities. Following the definition of production coefficients in IOT, ecological input and output coefficients can be derived:

(4) $\alpha = A^S X^{-1}$

(5) $\beta = A^D (F - E)^{-1}$

(6) $\mu = N^S X^{-1}$

(7) $\delta = N^D (F - E)^{-1}$

The coefficients defined in equations (4) and (6) show the consumption of natural resources A^S or the released pollutants N^S per unit of production X. In the same vein, equation (5) and (7) show the natural resource consumption A^D and the released pollutants N^D per unit of domestic final demand (F-E), where E stands for exports.

This ecological part of the model can be incorporated into the standard open input-output model. Final demand is determined exogenously. Moreover, it is assumed that the production coefficients v are stable parameters determining the economic adjustment process. Thus, changes in the values of production X can be calculated by using the production coefficients:

(8) $X = (I - v)^{-1} F$

where I is the identity matrix.

Moreover, there is a linear functional relationship between production and consumption of natural resources on the one hand and domestic final demand on the other. Hence, consumption of environmental goods and release of pollutants can be derived as follows:

$$(9) \quad A^S + A^D = \alpha(I - v)^{-1}F + \beta(F - E)$$

$$(10) \quad N^S + N^D = \mu(I - v)^{-1}F + \delta(F - E)$$

From equations (9) and (10), one can determine the natural resources used in production and consumption as well as the level of pollution caused by these activities if final demand and exports are given.

A number of such input-output models have already been used to analyze regional environmental issues, to evaluate the environmental consequences of government development programmes and to quantify the pollutant intensities of various final demand components (Forsund (1985)). The special merit of these models lies in their ability to consider both the direct and indirect economic and environmental effects with the latter induced by forward and backward linkages in production.

Nevertheless, such extended input-output models reveal two conceptual shortcomings. First, input-output models can be challenged on their assumption of fixed economic and ecological input and output coefficients. This implies a linear functional relationship among economic variables and between economic and ecological variables. If the model is used for structural analysis at one point in time, this assumption may be justified. However, policies aiming at the protection of tropical rain forests induce structural adjustments in production and final demand over time. With its fixed coefficients, ignoring substitution possibilities, the input-output model is too simple to be used for the economic analysis of tropical deforestation.

Secondly, the input-output model ignores the flows from producing sectors to factors of production (value added) and then to the entities such as government and households and finally back to demand for goods. As a result, secondary effects of e.g. a reduction of exports caused by import barriers for tropical hardwood are limited to those resulting from inter-industry linkages. However, by changing the level and structure of production in the economy, import barriers like other policies affect the level and distribution of disposable income. Changes in the level and distribution of income will bring about changes in the level and structure of production as well as in the production and consumption of environmental goods. These repercussions are ignored in the simple open static Leontief input-output model.

In the literature, it has, therefore, been proposed to incorporate ecological accounts into a Social Accounting Matrix (SAM) which expands the input-output accounts to include a complete specification of the circular flow in the economy (See Bojö/ Mäler/Unemo (1991)). Such an extended SAM will be discussed in the next section.

4. Incorporation of Ecological Aspects into a SAM-based Fix-price Model

Unlike the IOT, a SAM provides a complete picture of the circular flow of an economy.[1] Table 1 shows the elements of a SAM which has been extended to include environmental accounts. The central matrix encompassing the accounts 1-8 is confined to the description of the economic system and the respective linkages.

The last account reflects the extension of the SAM. The row of this account contains the raw materials and natural resources used in production and consumption. The column lists the wastes and pollutants released to the environment. All of these ecological variables are denoted in quantitities, while the economic section of the SAM is denoted in money terms, as it is the case in IOTs.

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[1] See King (1981) for an introduction to SAMs.

Table 1: Extended Social Accounting Matrix

Outgoing Input / Incoming Output	1 Activities	2 Commodities	3 Factors	4 Enterprises	5 Households	6 Government	7 Capital Accounts	8 Rest of the World	9 Total	10 Environmental Goods
1 Activities		Domestic Sales				Export Subsidies		Exports	Revenues	Outputs of Production
2 Commodities	Intermediates				Private Consumption	Government Consumption	Gross Investment		Demand	Outputs of Consumption
3 Factors	Value Added								Value Added	
4 Enterprises			Profits			Transfers			I	
5 Households			Wages & Salaries	Distributed Profits		Transfers		Transfers	N C O M	
6 Government	Indirect Taxes	Tariffs	Taxes	Corporate Taxes	Income Taxes				E	
7 Capital Account				Detained Profits	Household Savings	Government Savings		Net Capital Inflow	Savings	
8 Rest of the World		Imports							Imports	
9 Total	Costs	Absorption	Value Added	E X P E N	DITURES		Investment	Foreign Exchange Earnings		Outputs Pollution
10 Environmental Goods	Inputs for Production	Inputs for Consumption							Inputs Natural Resources	

Within the SAM framework, the simplest way to create a model is to assume that the various column coefficients of the central matrix are all constant, as in the input-output model. However, the matrix is square and the coefficients in every column sum to one. There are no exogenous elements and hence no multipliers. One approach to modelling is to specify one or more accounts as being exogenous. The result is a partitioned SAM with some columns specified as exogenous and some rows excluded. Let us assume that the expenditures of accounts 6-8 are exogenous and the expenditure coefficients of accounts 1-5 are the parameters which determine the economic adjustment process. For simplicity, let us also aggregate the first two accounts to the production accounts familiar from the IOT, and accounts 4 and 5 to household accounts. Then the commodity-market equilibrium underlying the SAM can be expressed as a system of linear equations:

$$(11) \quad \begin{vmatrix} X \\ W \\ Y \end{vmatrix} = \begin{vmatrix} v & 0 & f \\ w & 0 & 0 \\ 0 & y & 0 \end{vmatrix} \begin{vmatrix} X \\ W \\ Y \end{vmatrix} + \begin{vmatrix} e^X \\ e^W \\ e^Y \end{vmatrix}$$

or using the matrix form:

$$(12) \quad q = a^*q + e$$

where: a^* = matrix of SAM-coefficients (N + F + H,N + F + H)
v = matrix of input coefficients (N,N)
w = matrix of value added coefficients (F,N)
y = matrix of income distribution coefficients (H,F)
f = matrix of expenditure coefficients (N,H)
X = vector of production (N,1)
W = vector of value added (F,1)
Y = vector of household income (H,1)
e = vector of exogenous final demand and income (N+F+H,1)
q = vector of endogenous revenues (N+F+H,1)
N = number of sectors
F = number of factors
H = number of endogenous institutions

If a* is a non-singular matrix, the economic model yields the following solution:

$$(13) \quad q = [I - a^*]^{-1}e = Me$$

Including the ecological model as it is reflected in equations (4)- (7) yields:

$$(14) \quad A = A^S + A^D = (\alpha + \beta)\ Me + \beta(e - E)$$

$$(15) \quad N = N^S + N^D = (\mu + \delta)\ Me + \delta(e - E)$$

At first glance, the solution of the SAM-model resembles that of the extended open input-output model. The basic difference, however is, that equations (13)-(15) describe an economic-ecological model which is almost closed with respect to the generation, distribution und use of national income. The SAM model constitutes a simple disaggregated Keynesian model of the real sector of an open economy. The results of such a model do not only reflect changes in ecological variables resulting from inter-industry linkages but also take account of income effects on environmental goods.[1]

However, just like the input-output model the SAM-model builts on strong assumptions. Both models are entirely demand driven and completely neglect issues of resource allocation, productivity and factor utilization. With its fixed coefficients, the SAM model ignores substitution possibilities in consumption, production, imports, and exports triggered by changes in relative prices. It also ignores possibilities for partial shifting of the incidence of taxes, tariffs, and subsidies through interactions between supply and demand. Finally, the model does not capture the behaviour of economic agents, interacting across markets in response to shifts in price signals, which constitute an important mechanism by which government policies affect the economy.

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[1] Wiebelt (1990c) estimated Keynesian-type SAM multipliers for Peninsular Malaysia and contrasted them with multipliers derived from an open Leontief model.

Given these restrictions, it is not possible to derive meaningful results on the environmental variables resulting from adjustments in the economy. However, it is especially this aspect which is at the center of interest. In order to analyze both environmental effectiveness and economic efficiency of government interventions one needs a model, in which economic agents engage in markets and therefore react to relative prices. The next step in the research agenda, therefore, is to use the extended SAM accounting framework as a basis for constructing a computable general equilibrium model.[1] Such a model incorporates price-reponsive supply and demand behaviour, and its solution yields relative prices as well as quantities and all the nominal accounts in the SAM. If combined with our ecological sub-model, a CGE model can provide a useful framework for doing policy analysis and to quantify both the economic and environmental consequences of private economic activities and government intervention. An extended CGE-model featuring an integration of economic and ecological spheres will be presented in the next section.

5. Ecological CGE-Models

The economy of a developing country can be depicted as a system of interdependet markets for commodities, factors and foreign exchange.[2] The main equations of such a model together with the

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[1] Among others, Pyatt and Thorbecke (1976) point out that for the numerical specification of a macroeconomic model, a SAM provides a useful vehicle for organizing data of different origin.

[2] For a discussion of the mathematical structure of CGE models, the reader is best referred to Adelman and Robinson (1978), Dervis et al. (1982) and Taylor et al. (1980). The model discussed in this section is a variant of that developed by Dervis et al. (1982). A more detailed formal statement and description of this model is given in Wiebelt (1989). The usefulness of CGE models for the analysis of environmental problems in developing countries is discussed by Devarajan (1990).

variable names are listed in Tables 2 and 3. The activities of economic agents, i.e. producers, consumers, government, rest of the world, are captured by microeconomic behavioural equations as well as institutional functions, e.g. tax revenue function, and technical relationships, as they follow from the production function. The latter also include the ecological input and output coefficients, which will be assumed constant.

The production function [equation (1)] in the combined, economic and ecological model not only includes capital and labour but also land (forest and non-forest) as primary factors in agriculture, forestry, mining etc. Since the problem is to lower the use of forest land, some substitutability between this land and other primary factors of production and intermediates (like fertilizer in agriculture) should be incorporated. Assuming that the capital stock is constant and immobile across sectors in the short run, intermediate demand, employment, land use and output are determined in each economic sector by producers maximizing profits given the prevailing wages, rental rates and output prices, as well as the tax rates on factors and in production [equations (1), (8), (10), (11), and (31)].

The household sector is disaggregated into various groups of households by using socio-economic criteria. Depending on their factor endowment, these households derive their income from wages, capital income, rents for land and government transfers [equations (19)-(21)]. If land titles (for forest land) are restricted to government, this implies $T^{F*} = 1.0$ in equation (20) and (22). The gross income which the households receive is used for consumption, savings, as well as for taxes and social insurance payments. The demand for consumer goods (investment goods) is a function of income (savings) and the respective prices [equations (6), (19)-(21), (23), (24), (32), and (34)].

The government finances its budget by raising direct and indirect taxes, tariffs, by profits of state-owned enterprises as well as transfers from abroad [equation (22)]. Government expenditures

Table 2: Components of the Computable General Equilibrium Model (macroeconomic version)

Real Flows

(1) $X(V^D, L^D, F^D, K^{D*})$ Production

(2) $X(E, D^S)$ Export transformation

(3) $Q^D(M, D^D)$ Import aggregation

(4) $M/D^D = f_1(P^m, P^d)$ Import demand

(5) $E/D^S = f_2(P^e, P^d)$ Export supply

(6) $C^D(P^q, C^+)$ Consumer demand

(7) $Z^D(P^q, Z^+)$ Investment demand

(8) $V^D(R, W, P^q, P^x)$ Intermediate demand

(9) $Q^D = C^D + Z^D + V^D + G^{D*}$ Domestic demand

(10) $L^D(R, W, P^x, P^q)$ Labour demand

(11) $F^D(R, W, P^x, P^q)$ Land demand

Ecological Inputs and Outputs

(12) $A^S(F^D)$ Ecological inputs

(13) $N^S(F^D)$ Ecological outputs

(14) $A^D(C^D, Z^D, G^{D*})$ Ecological inputs

(15) $N^D(C^D, Z^D, G^{D*})$ Ecological outputs

Market Equilibrium

(16) $D^D - D^S = 0$ Product market

(17) $L^D - L^{S*} = 0$ Labour market

(18) $F^D - F^{S*} = 0$ Land market

Nominal Flows

(19) $Y^{L+} = W \cdot L^{S*} \cdot (1 - T^{L*})$ Labour income

(20) $Y^{F+} = R \cdot F^{S*} \cdot (1 - T^{F*})$ Rental income from land

(21) $Y^{K+} = P^x \cdot X - W \cdot L^D - R \cdot F^D - P^q \cdot V^D$ capital income

(22) $Y^{G+} = T^{L*} \cdot W \cdot L^S + T^{K*} \cdot Y^{K+} + T^{F*} \cdot Y^{F+}$

$+ r(T^{m*} \cdot P^{Sm*} \cdot M - T^{e*} \cdot P^{Se*} \cdot E)$

$+ T^{d*} \cdot P^d \cdot D^S$ Government revenues

(23) $C^+(Y^{L+}, Y^{K+}, Y^{F+})$ Consumption function

(24) $S^{P+} = Y^{L+} + Y^{K+} + Y^{F+} - C^+$ Private savings

(25) $M^+ = P^{Sm*} \cdot M$ Imports in foreign currency

(26) $E^+ = P^{Se*} \cdot E$ Exports in foreign currency

Price Equations

(27) $P^m = r \cdot P^{Sm*} \cdot (1 + T^{m*})$ Import price

(28) $P^e = r \cdot P^{Se*} \cdot (1 + T^{e*})$ Export price

(29) $P^q(P^m, P^d)$ Consumer price

(30) $P^x(P^e, P^d)$ Producer price

(31) $P^n = (1 - T^{d*})(P^x, P^q)$

Macroeconomic Equilibrium

(32) $S^{P+} + S^{G+} + r \cdot B^* - Z^+ = 0$ Savings = investment

(33) $Y^{G+} - P^q \cdot G^{D*} - S^{G+} = 0$ Government budget

(34) $M^+ - E^+ = B^*$ Trade account

(35) $f_3(P^d, P^m, W, R, P^e) = P^*$ Price index

Identities

(33) $P^x \cdot X = P^e \cdot E + P^d \cdot D^S$ Value of production = revenues

(34) $P^q \cdot Q = P^m \cdot M + P^d \cdot D^D$ Demand = absorption

(35) $P^x \cdot X = W \cdot L^D + R \cdot F^D + Y^{K+} + P^q \cdot V^D$ Revenues = costs

(36) $P^q \cdot C^D = C^+$ Consumer demand = expenditures

(37) $P^q \cdot Z^D = Z^+$ Investment demand = expenditures

(38) $A^S + A^D = N^S + N^D$ Ecological inputs = ecological outputs

Table 3: Variables of the Computable General Equilibrium Model

Endogenous Variables

X^S	= domestic production	P^m	= domestic price for imports
D^S	= domestic supply	P^e	= domestic price for exports
D^D	= domestic demand	P^x	= producer price
E	= domestic exports	P^d	= consumer price for goods
M^D	= import	P^q	= consumer price
Q^D	= domestic absorption	P^n	= net price
V^D	= demand for inputs	W	= wage rate
L^D	= labour demand	R	= rental rate of land
F^D	= demand for land	r	= nominal exchange rate
C^D	= real consumption	Y^{G+}	= government revenues
Z^D	= real investment	S^{P+}	= private savings
Y^{L+}	= labour income	S^{G+}	= government savings
Y^{F+}	= rental income from land	C^+	= nominal consumption
Y^{K+}	= capital income	Z^+	= nominal investment
M^+	= imports in US$	A^S	= ecological inputs in production
E^+	= exports in US$	A^D	= ecological inputs in consumption
		N^S	= ecological outputs from production
		N^D	= ecological outputs from consumption

Exogenous Variables

L^{S*}	= labour supply	B^*	= trade account in US$
F^{S*}	= land supply	$P^{\$m*}$	= import price in US$
G^{D*}	= real government consumption	$P^{\$e*}$	= export price in US$
T^{L*}	= income tax rate	P^*	= price index
T^{K*}	= corporation tax rate		
T^{m*}	= tariff rate		
T^{e*}	= export subsidy rate		
T^{d*}	= sales tax rate		

Nominal variables are indicated by a "+"; exogenous variables are indicated by a "*". Subscripts d, m, e, x and q refer to goods produced and consumed domestically, imports, exports, goods produced domesticallly as well as goods consumed domestically (D, M, E, X and Q). The subscripts D and S stand for demand and supply, L and K for labour and capital, P and G for private and government. The macroeconomic version of the model encompasses 34 endogenous variables and 35 equations, of which 34 are independent. The production function and the import aggregation function (1) and (3) are CES-type functions. The export transformation function is specified as a CET-function. Equations (4), (5), (8), (10) and (11) are the respective demand functions derived from first-order-conditions for minimum costs. Equations (29) and (30) are dual cost functions corresponding to equations (3) and (2). Equation (35) defines the numeraire.

include transfers for pensions, unemployment benefits and other social expenditures for private households on the one hand (not explicitly shown in Table 2) as well as consumption and investment expenditures [equations (7), (9), and (33)].

With respect to foreign trade, the model assumes a small economy, in which both import supply and export demand are perfectly elastic [equations (27) and (28)]. As usual in appropriately aggregated CGEs for developing countries, imported goods and locally produced goods belonging to the same product category are treated as imperfect substitutes according to the Armington (1969) assumption [equations (3), (4) and (29)]. In the same vein, differences in quality are assumed to prevail between domestic sales and exports of the same product category [equations (2), (5), and (30)], as it has been proposed by Powell and Gruen (1968).

Unlike commodity markets [equation (16)], the labour market [equation (17)] must not equilibriate supply and demand, if labour demand is rationed by minimum wage levels resulting from collective bargaining or government intervention. Under these conditions, unemployment or underemployment will prevail in general equilibrium.

In this respect, the model follows the tradition of developing-country-models, as they have been constructed by Adelman and Robinson (1978) as well as Dervis, deMelo and Robinson (1982). The theoretical underpinning of these models can be traced back to the theory of dualism in labour markets. Accordingly, there is a small official sector and a large inofficial sector, while linkages between these sectors are weak. In the same vein, the model assumes that there are two completely different labour markets, i.e. an agricultural labour market and a labour market for the manufacturing industry. The latter may be further disaggregated into markets for skilled and unskilled labour.

In each of these labour markets, labour supply is assumed to be constant in the short run. In the agricultural labour market and the labour market for skilled workers, it is the wage rate which adjusts. By contrast, the labour markets for unskilled labour can be in disequilibrium, which is equivalent to unemployment or underemployment. Though the labour demand is elastic with respect to changes of wages, the scope of adjustment is restricted by real or nominal minimum wage rates.

Another disequilibrium can arise in the current account [equation (34)], when restrictive foreign exchange regulations cause an overvaluation of the fixed exchanged rate. Such a disequilibrium can be sustained, as long as economic agents deliberatey equilibriate foreign exchange losses by capital transfers.

Finally, the suboptimal production decisions in natural-resource-based activities which follow from the lack of property rights and which is behind deforestation has to be modeled. In the CGE model this can be done by removing the first order condition [equation (11)] for some sectors (e.g. agriculture, forestry) and replacing it with one which reflects suboptimal behaviour in these sectors. As suggested by Devarajan (1990), sectors can be splitted into individual firms, each making its output and demand decision based on the Cournot-Nash conjecture. Alternatively, the land marekt can be modeled similar to the market for unskilled labour where an institutionally fixed price ceiling for forest land avoids price adjustment. In both cases the resulting output of the resource-based sectors is suboptimal. With fixed ecological input and output coefficients, the quantity of natural resources used and pollutants produced are determined [equations (12)-(15)].

The implementation of such an ecological CGE-model requires substantial empirical research, as the entire structure of the theoretical model has to be quantified at least for one base year. This base year is supposed to reflect the state of general equilibrium. A part of this model structure can be derived from national account statistics and satellite systems. In addition, a number of parameters have to be estimated, i.e. policy variables as well as parameters of the technical and ecological functions and behavioural equations discussed above. Using a computer-model version of the CGE-model, it is possible to calculate all equilibrium prices or - in cases where prices are exogenously given - quantities actually traded. These prices and quantities, in turn, determine the allocation of resources, the distribution of income and eventually the consumption (and production) of environmental goods which follows from the fixed ecological input and output coefficients.

Given such a quantified model structure, economic changes as well as changes in environmental and economic policies can be analyzed through model simulation by altering exogenous variables and calculating a new general equilibrium. Thereafter, the new equilibrium can be compared with the initial equilibrium (comparative static approach).

In order to carry out comparative dynamic simulations the model described above has to be extended. Some variables that have been assumed constant in the short run, i.e. sectoral capital stocks and labour supply, are allowed to change endogenously over time. Other variables, e.g. world market prices are adjusted exogenously. Changes in sectoral capital stocks can be derived from a submodel depicting investment demand in the particular sectors. Basically, there are two ways to model the allocation of investment by sectors of destination. Firstly, it can be assumed that in the absence of functioning capital markets firms cannot lend capital or issue stocks. Hence, the structure of investment is determined by the sectoral shares in aggregate profits. Given this formulation of the investment demand model, repercussions of policy measures on sectoral investment are excluded, e.g. investment reallocations in the wood industry caused by declining export demand.

Secondly, it is possible to include an endogenous investment model, which has, however, to consider the poor data base on financial transactions in developing countries. In this investment model, sectoral shares in aggregate investment are adjusted 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:

$$(39)\ H(t) = SP(t-1) + \mu SP(t-1)\left[\frac{R(t-1) - AR(t-1)}{AR(t-1)}\right]$$

where H is the share in the investment budget, SP denotes the sectoral share in aggregate profits, R is the sectoral return on capital, AR is the average return on capital and μ is a mobility parameter for investable funds.

The following example illustrates the mechanism of investment allocation: In case of an import boycott for tropical hardwood and a respective reduction of export demand relative to other goods, the relative price of tropical wood will decline, thus lowering the profitability of the forestry sector and the wood industry. As a consequence, firms will prefer a reduction of their capital stock and reduce investment, while other sectors will increase their investments.

Another aspect of the dynamic version of the model is the modeling of linkages between the rural population size and urban population. Basically, the separation of the labour market into various submarkets, as it has been done above, can be justified on the grounds that in reality these particular markets, especially the rural and the urban sector, reveal substantial differences in living conditions, work experience, skills, social achievements, working conditions etc. Since there is substantial migration from rural areas to cities and migration from non-forest areas into rain forests, the rural and the urban sector and the respective segments of the labour market cannot be regarded as being isolated in a dynamic model. Hence, migration and population growth has to be taken into account by introducing a migration function, which explains migration as dependent on wage differentials for rural labour and unskilled labour employed in manufacturing. As a result, labour supply in these segments of the labour market does not only depend on the natural growth rate of population but also on cityward migration. As the following equations show, labour supply in period t+1 equals

(40) $\bar{L}_1^S(t+1) = (1+g_1)\bar{L}_1^S(t) - MIG(t)$

(41) $\bar{L}_2^S(t+1) = (1+g_2)\bar{L}_2^S(t) + MIG(t)$

where

$\bar{L}_1^S$ $(\bar{L}_2^S)$ = rural (urban unskilled) labour

$g_i(g_2)$ = natural growth rate and rural (urban unskilled) labour supply

MIG = number of migrants

(42) $MIG(t) = e(w_2^e/w_1 - 1)\bar{L}_1^S(t)$

and

(43) $w_2^e = w_2(L_2^D/\bar{L}_2^S)$

where

e = migration elasticity

w_2^e = expected wage

w_1 = wage in agriculture

L_2^D = demand for unskilled labour in manufacturing

Hence, the larger the wage differential and the higher the migration elasticity, the more cityward migration is expected to occur in period t. In the same vein, migration betwen non-forest areas and forest areas can be expressed as a function of wage differentials and differentials in prices for land.

Both the dynamic and the comparative static model formulation can serve as a tool for policy analysis. Given the structure of the comparative static model, this formulation can only be used for short-run policy analysis, while medium and long-term adjustment have to be analyzed by using the comparative-dynamic model. Basically, the models are capable to take into consideration all economic and most non-economic policy measures. For instance one of the usual policy instruments in industrial policy is the variation of corporate taxes and depreciation allowances. Following Mahar (1989) and Bojö, Mäler and Unemo (1990), tax and depreciation allowances have been effective policy instruments fostering the industrialization and colonization of the Amazonian rain forest in Brazil. Assuming that the sectoral capital stock is given in the short run, these policy measures affect sectoral profits and thus returns on investment. By definition, this has no effect on the intersectoral allocation of capital. Hence, in the short-run an increase or decline in sectoral output resulting from alterations in these policy instruments is only due to reallocation of labour, which reacts elastically. Given a dynamic formulation of the model, a change in sectoral profitability leads to adjustments in investment activities thus affecting sectoral capital stocks. The extent to which a reduction of corporate taxes and increases in depreciation allowances leads to shifts in sectoral output and deforestation depends on the substitutability of capital and labour following from the production function.

In the same vein, a reallocation of land can be depicted in the model. According to Amelung and Diehl (1991) the distribution of land impacts on deforestation, since a large number of landless farmers are forced to settle down on marginal soils in tropical rain forests. If these landless farmers are given land outside tropical forest, this migration pressure can be reduced. In the ecological CGE model this aspect can be taken into account by disaggregating land as a production factor into land reserves in tropical forests and land reserves in non-forest areas. By considering different degrees of substitutability between these two categories of land, changes in land titling legislation as well as land reforms can be incorporated into the model.

Moreover, changes in agricultural policies impact on deforestation. There are a number of agricultural products which suffer from government-induced discrimination (Wiebelt et al. (1991)). If this discrimination is lowered, it can be expected that the demand for land increases thus fostering the conversion of tropical forests into agricultural land. In the same vein, there are a number of agricultural products, that are favoured in terms of net effective protection, e.g. food crops in Malaysia, livestock production in Brazil. A reduction of this protection could decrease the demand for land and thus tropical deforestation. To which extent a move towards a more neutral trade regime impacts on deforestation, can only be analyzed in such a CGE framework, since rising land demand in one agricultual subsector can be offset by declining demand for land in another subsector.

Furthermore, domestic environmental policy measures like resource use taxes and so-called Pigout-taxes can be incorporated into the model. On the one hand, the clearing of land used for agricultural purposes can be subject to taxation. This would eventually cause lower returns on tropical forest land compared to land outside tropical forest areas. Depending on the substitutability between these two land categories deforestation can be expected to decrease. Moreover, resource use taxes can be levied on other tropical forest resources used by particular sectors, e.g. mineral sources, hydroelectricity and tropical hardwood. These resources are treated as ecological inputs in the CGE-model. If the goverment introduces a resource use tax, this leads to a substantial adjustment in all sectors of the economy.

Finally, the effects of international policy measures like compensatory finance for forest conservation, debt-for-nature swaps and import barriers for tropical hard wood can also be simulated in the model. All of these measures incur direct effects on transactions in the current account, changes in foreign exchange and the capital account. Import barriers result in a decline in export demand and are introduced by altering the parameters in export demand functions. Compensatory finance are treated as unilateral transfers, while alternative conditionalities on the use of these transfers and their impact on the real side of the economy can be analyzed. Debt-for-nature swaps cause a reduction of debits in the capital account.

6. Summary and Conclusions

As this paper has shown, the effects of alternative policies for conserving the tropical rain forest cannot be evaluated in a partial-equilibrium framework. There are a number of sectors using rain forest resources jointly and successively, thereby depleting the rain forest ecosystem. Hence, an effective policy approach aiming at rain forest protection has to consider a number of sectors without neglecting intersectoral linkages. The latter, however, are neglected in a partial equilibrium framework. Moreover, a number of international policy instruments for rain forest protection, e.g. trade barriers against tropical timber, compensatory financing, debt-for-nature swaps, affect the economy of the tropical countries as a whole. Hence, a microeconomic analysis of one market is not helpful because it neglects intersectoral interdependencies. Moreover, partial analysis cannot evaluate the economic costs resulting from policies aiming at rain forest protection. Since the rain forest is an economic resource and an input for the tropical countries' development, such policies and the subsequent decrease of rain forest exploitation may result in unemployment, decline in national income and shrinking exports. As this paper shows, partial analysis is not well assessing both environmental effectivenes and economic costs of alternative policy measures.

Intersectoral linkages, however, can be modelled by using input-output analysis, social accounting matrices or computable general equilibrium models. All of these model can be extended in such a way that they depict both the model of a tropical country's economy and the functional relationship betwen the economy and the ecology. Unlike the input-output-model the SAM-model takes account of income effects on the environment. Both models, however, use very restrictive assumptions regarding the substitutability of factors of production. Hence, these models can be used for structural analysis. By contrast, computable general equilibrium models allow for the reallocation of factors, thus showing possible adjustments resulting fom conservation measures. Again, comparative-static approaches and comparative dynamic approaches can be distinguished. The major difference is that the latter take into account changes in environmental quality resulting from growth in labour supply and intersectoral capital stocks. Given such a formulation, computable general equilibrium models can serve as a useful tool for policy analysis and policy design in the future.

References

Ahmad, Y.J., S.E. Sarafy, E. Lutz (Eds.) (1989), Environmental Accounting for Sustainable Development. The World Bank, Washington, D.C.

Adelman, I. and S. Robinson (1978), Income Distribution Policy in Developing Countries: A Case Study of Korea. Oxford: Oxford University Press.

Amelung, T. (1989), Zur Rettung der tropischen Regenwälder: Eine kritische Bestandsaufnahme der wirtschaftspolitischen Lösungsvorschläge. Die Weltwirtschaft, Nr. 2, 152-165.

Amelung, T., M. Diehl (1991), On the Economic Causes of Deforestation in Tropical Countries. Interim Report. Kiel Institute of World Economics, mimeo.

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

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

Brünig, E.F. (1989), Die Erhaltung, nachhaltige Vielfachnutzung und langfristige Entwicklung der Tropischen Immergrünen Feuchtwälder (Regenwälder). Arbeitsbericht. Institut für Weltforstwirtschaft und Ökologie, Bundesforschungsanstalt für Forst- und Holzwirtschaft, Hamburg.

Crutzen, P.J, W.M. Hao und M.H. Liu (1989), Estimates of Annual and Regional Releases of CO_2 and other Trace Gases to the Atmosphere from Fires in the Tropics. Proceedings of the Third International Symposium on Fire Ecology, Freiburg University, Freiburg, 16-20 May 1989. Berlin, Heidelberg, New York.

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 a WIDER conference on "The Environment and Emerging Developing Issues", Helsinki, September 3-7, 1990.

Enquete-Kommission "Vorsorge zum Schutz der Erdatmosphäre" (EK) (1990), Zweiter Bericht zum Thema "Schutz der tropischen Regenwälder". Deutscher Bundestag, 11. Wahlperiode, Drucksache Nr. 11/7220, 24.5.1990.

Forsund, F.R. (1985), Input-Output Models, National Economic Models, and the Environment. In: Arrow, K.J. and M.D. Intriligator (Eds.), Handbook of Natural Resource and Energy Economics, Vol. I.. Amsterdam et al., 325-341.

Frey, B.S. (1980), Umweltökonomik. In: Albers, W. (Hrsg.), Handwörterbuch der Wirtschaftswissenschaften. Stuttgart et al., 47-58.

Gehrig, G. (1980), Input-Output-Analyse. In: Albers, W. (Hrsg.), Handwörterbuch der Wirtschaftswissenschaften. Stuttgart et al., 215-233.

Gehrig, G. (1986), Use of Input-Output-Techniques in Environmental Research. In: Liber amicorum Professor Doctor Piere-Henri Virenque. Antwerpen, 45-60.

Hall, C.A.S. et al. (1989), A New Estimate of Carbon Release from Land Use Change in the Tropics based on a New Calculation of Biomass. U.S. Department of Energy. Washington, D.C.

Houghton, R.A., D.S. Lefkowitz, D.L. Skole (1990), Changes in the Landscape of Latin America between 1850 and 1985. A Progressive Loss of Forests, forthcoming.

King, B.B. (1981), What is a SAM? A Layman's Guide to Social Accounting Matrices. World Bank Staff Working Paper No. 463. Washington, D.C.

Mahar, D.J. (1989), Deforestation in Brazil's Amazon Region: Magnitude, Rate, and Causes. In: Schramm, G., J.J. Warford (Eds.), Environmental Management and Economic Development. Baltimore, 87-116.

Myers, N. (1989a), The Environmental Basis of Sustainable Development. In: Schramm, G., J.J. Warford (Eds.), Environmental Management and Economic Development. Baltimore, 56-68.

Myers, N. (1989b), Deforestation Rates in the Tropics and their Climatic Implications. Friends of the Earth. London.

Oberndörfer, D. (1988), Schutz der tropischen Regenwälder durch Entschuldung. Perspektiven und Orientierungen (Schriftenreihe des Bundeskanzleramtes), Bd. 5, München.

Oberndörfer, D. (1989), Schutz der tropischen Regenwälder (Feuchtwälder) durch ökonomische Kompensation. Freiburger Universitätsblätter, Heft 105, Sept. 1989, 91-119.

Pearce, D.W., R.K. Turner (1990), Economics of Natural Resources and the Environment. London.

Pearce, D., E. Barbier, A. Markandya (1990), Sustainable Development. Economics and the Environment in the Third World. Hants.

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

Pretzsch, J. (1989), Der Beitrag der Holzexploitation und des Holzexports zur allgemein wirtschaftlichen Entwicklung von Tropenländern. Freiburger Universitätsblätter, Heft 105, Sept. 1989, 77-90.

Pyatt, G., E. Thorbecke (1976), Planning Techniques for a Better Future. Geneva: International Labour Office.

Reilly, W.K. (1990), Debt-for-Nature Swaps: The Time has Come. International Environmental Affairs, Vol. 2, No. 2, 134-139.

Repetto, R, W. Magrath, M. Wells, Ch. Beer, F. Rossini (1989), Wasting Assets: Natural Resources in the National Income Accounts. World Resource Institute, Washington, D.C.

Ruitenbeek, H.J. (1990), The Rain Forest Supply Price: A Step Towards Estimating a Cost Curve for Rain Forest Conservation. London School of Economics, Development Research Programme, Discussion Paper No. 29, September 1990.

Ryll, A., D. Schäfer (1988), Satellitensystem "Umwelt". In: Reich, U.-P., C. Stahmer u.a., Satellitensysteme zu den Volkswirtschaftlichen Gesamtrechnungen, Band 6 der Schriftenreihe Forum der Statistik, hrsg. vom Statistischen Bundesamt. Stuttgart und Mainz.

Steinlin, H. (1989), Tropenwälder. Freiburger Universitätsblätter, Heft 103, Sept. 1989, 23-62.

Taylor, L., E.L. Bacha, E.A. Cordoso, F.J. Lysy (1980), Models of Growth and Distribution for Brazil. Oxford: Oxford University Press.

Wiebelt, M. (1989), How Does Industrial Protection Affect the Agricultural Sector? A Quantitative General Equilibrium Analysis for Peninsular Malaysia. Kiel Working Paper No. 380, Kiel Institute of World Economics, Kiel.

Wiebelt, M. (1990a), The Impact of Industrial Protection on Agriculture: A General Equilibrium Analysis for Peninsular Malaysia. European Review of Agricultural Economics, Vol. 18, 61-83.

Wiebelt, M. (1990b), The Shifting of Protection in Developing Countries: A Comparative Analysis for Zimbabwe, Malaysia and Peru. Kiel Working Papers No. 441, Kiel Institute of World Economics, Kiel, September 1990.

Wiebelt, M. (1990c), Social Accounting Matrix (SAM) als Instrument der Strukturanalyse. In: Gans, O. und I. Evers (Eds.), Handbuch der volkswirtschaftlichen Beratung. Baden-Baden: Nomos.

Wiebelt, M., R. Herrmann, P. Schenck, R. Thiele (1991), Discrimination Against the Agricultural Sector in Developing Countries? (Kieler Studien), Mohr, Siebeck: Tübingen (in process).

World Resource Institute (1985), Tropical Forests: A Call for Action. Report of an International Task Force convened by the World Resource Institute, The World Bank, and the United Nations Development Programme. Washington, D.C.