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The appropriateness of CGE modelling in analysing the problem of deforestation

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Abstract

Purpose – The paper reviews recent developments in utilising computable general equilibrium (CGE) models to analyse forestry policies. The paper highlights the application of CGE modelling to deforestation and forestry issues.

Design/methodology/approach – The analysis is carried out by comparing different CGE models available in the literature, which have analysed the economic consequences of deforestation and changes in forestry policies.

Findings – The use of CGE models in analysing forestry issues is still in its early stages. There is room for innovation and improvement in the various models used.

Practical implications – The paper emphasises the relevance of general equilibrium analysis in the evaluation of both micro- and macro-economic policies on forestry. It encourages researchers to use general equilibrium analysis in their study of environmental problems.

Originality/value – The paper highlights the contribution and possible benefits of utilising CGE models in analysing environmental problems such as deforestation, especially in the context of environment-economics trade-off.

Keywords Economic policy, Forestry, Modelling

Paper type General review

1. Introduction

Studies on deforestation have been conducted using partial equilibrium methods but the increasing trade-off between economic and environmental goals considers these methods to be inadequate. On the contrary, general equilibrium models are capable of evaluating economy-wide issues. The increasing application of general equilibrium models to problems in resource and environmental economics implies that computable general equilibrium (CGE) models can be useful in analysing deforestation issues. In fact, there are a number of CGE models constructed to analyse deforestation, stumpage tax and timber supply issues. The main objective of the paper is to examine the appropriateness of employing general equilibrium analysis in assessing deforestation in general. The remainder of the paper is organised as follows: Section 2 outlines the characteristics of CGE models and their relevance to the formulation of environment-related policies. Section 3 gives a brief discussion of the data requirements. Section 4 summarises CGE models constructed with special reference to the forestry sector and evaluates their importance in the formulation of sound

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forestry policies. Section 5 summarises the weaknesses of existing models and outlines a program for further research.

2. A case for CGE modelling

Economy-wide CGE models allow endogenous interaction of all sectors in the economy. These models are generally based on a set of input demand and output supply equations. There are equations representing the behaviour of economic agents such as consumers, investors, government and the foreign market. Most modellers rely on a specific year's (benchmark) equilibrium data set to specify the numerical relationships in the model. The basic difference between partial and general equilibrium analysis is in the treatment of prices. In the former, all prices other than the price of the good being studied are assumed to remain fixed whereas in the latter, all prices are variable and all markets clear. Hence, secondary effects are ignored in partial equilibrium models.

There are advantages in resorting to CGE models in examining environment-related problems (Alfsen, 1991; Boyd and Newman, 1991; Clarete and Roumasset, 1986; Decaluwe and Martens, 1988; Semboja, 1994; Uri and Boyd, 1993). Firstly, general equilibrium models represent a useful tool and framework for multi-sectoral policy formulation. For example, in Johansen-type CGE models, there are conditions to be satisfied (e.g. price homogeneity and real homogeneity tests). All economic agents maximise their behaviour, subject to the relevant constraints, allowing for all markets to clear, and transactions are conducted at equilibrium prices. The quantity supplied must exactly match the quantity demanded for every factor of production and for all goods and services consumed. Hence, all interactions among markets are taken into account and, consequently, all interrelationships between sectors are explicitly considered. Secondly, the CGE modelling approach performs the analysis at a disaggregated level. It can identify sector specific effects of the policy in question. The level of disaggregation can vary depending on the issues being studied. Lastly, many environmental problems and their solutions represent long-term phenomena. For example, forestry rotation periods cover 30-80 years.

CGE models can be solved for short- and long-run outcomes. Dynamic or intertemporal models have been developed to accommodate long-run effects as well as for forecasting. Another advantage of using CGE models in analysing environmental problems such as deforestation is their ability to rank welfare effects of different policy instruments (Conrad and Schröder, 1993). The unreliability of forestry data may cast some doubts on the quantitative results of CGE models but not on the qualitative results. CGE models are based on microeconomic theory, which tends to be more transparent than many macroeconomic models. In addition, the maximising behaviour of economic agents determines which variables, either endogenous or exogenous, are to be modelled.

Nevertheless, CGE models have their limitations (Dixon and Parmenter, 1994; Bandara, 1991). Firstly, many CGE models rely on neo-classical assumptions of perfect competition and production functions characterised by constant returns to scale. However, some CGE modellers (Persson, 1994; Persson and Munasinghe, 1995) have incorporated assumptions other than the traditional assumptions of neo-classical economics. Nonetheless, different CGE models analyse different economic problems, hence the use of neo-classical assumptions might be applicable to some. Secondly, traditional CGE models are real models. In other words, these models are primarily interested in real variables in the economy and money is considered neutral. Yet there are CGE models (Robinson, 1991) that incorporate a monetary sector, generally called financial CGE models. Thirdly, static CGE models are unable to model the long-run development process of economies. This requires the development of dynamic CGE models[1]. Nevertheless, the issue of dynamics does not only confront CGE models but macroeconomic models as well. Fourthly, the data and parameter values used are sometimes questionable. CGE models are criticised on the grounds of data quality to the extent that less developed countries (LDCs) do not generally have reliable data. In addition, most of the parameter values (i.e. elasticities) are at best guesses and are not based on appropriate econometric studies. At present, some of these issues are being addressed by the development of social accounting matrices in LDCs, the basic data needed in a CGE model. When there are no econometric estimates for parameter values, the plausibility of these guesses can be determined through sensitivity analysis[2]. Lastly, the fact that the estimated results from a CGE simulation are difficult to explain to policy makers makes CGE models unattractive. These models are viewed as black boxes which do not facilitate the explanation of what happens inside. Dixon *et al.* (1982) attempted to overcome this limitation by providing the back-of-the-envelope (BOTE) technique which involves simple calculations to show how the model results are derived.

As CGE models are increasingly being applied to environmental problems, the failure of these models to analyse welfare effects accurately is a concern[3]. Dixon and Parmenter (1994) argued that CGE models assume that welfare changes arise only from a reallocation of a given quantity of scarce factors of production. These models also normally assume that the proposed policy change has no effect on the total employment of labour and capital. Welfare implications are measured in terms of the variation in consumer income, which translates to the same variation in consumer's utility. The welfare calculations derived from CGE results produce small or unconvincing numbers (Dixon and Parmenter, 1994). Nevertheless, CGE modelling has still a lot of potential and capability for developing new methodologies to address its limitations.

A typical CGE model in levels can be represented as:

$$F(Z) = 0 \tag{1}$$

where F is a vector of m differentiable functions of the Z vector of size n. It is assumed that the number of variables, n, is greater than the number of equations m. Behavioural equations representing the demands by industries, investors, households and foreigners are represented in equation (1). Constraints like zero-profits and market clearing are imposed on the equation system.

The system can be very large and can involve a wide variety of nonlinear functions. From a computational point of view, it might be intractable. The approach pioneered by Johansen resolves this computational difficulty. Johansen's approach is to derive from equation (1) a system of linear equations in which the variables are percentage changes or changes in the components of Z. The derived system is represented as:

$$A(Z)_z = 0 \tag{2}$$

where $A(Z)$ is a $m \times n$ matrix whose components are partial derivatives or elasticities of F evaluated at Z. The $n \times 1$ vector z is interpreted as the percentage changes or changes in Z. The Johansen-style computation is generated by replacing the variable matrix $A(Z)$ on the left-hand side of equation (2) by a fixed matrix, $A(Z^0)$, where Z^0 is the vector of initial values of Z[4]. Then equation (2) is rewritten as:

$$A_y(Z^0)z_y + A_x(Z^0)z_x = 0 \tag{3}$$

where z_y is the $m \times 1$ sub-vector of endogenous components of z, z_x is the $(n-m) \times 1$ sub-vector of exogenous components, and $A_y(Z^0)$ and $A_x(Z^0)$ are appropriate sub-matrices of $A(Z^0)$, that is $A_y(Z^0)$ is the $m \times m$ matrix formed by the columns of $A(Z^0)$ corresponding to the endogenous variables, and $A_x(Z^0)$ is the $m \times (n-m)$ matrix formed by the columns corresponding to the exogenous variables[5]. To solve for z_y in terms of z_x, it is assumed that the relevant inverse exists[6], giving:

$$Z_y = -A_y^{-1}(Z^0)A_x(Z^0)Z_x \tag{4}$$

or

$$z_y = B(Z^0)z_x \tag{5}$$

with z in percentage changes, the typical element, $B_{ij}(Z^0)$, of $B(Z^0)$ is the elasticity evaluated at Z^0 of the ith endogenous variable with respect to the jth exogenous variable.

3. Data requirements for CGE models

The basic data source of CGE models is either the social accounting matrix (SAM) or the input-output (I-O) table or both. In addition, estimates of a number of elasticity parameters and coefficients are needed for the construction of a database (e.g. elasticities of substitution between domestic and foreign goods, between primary factors, export demand elasticities and product-product transformation parameters).

3.1 Social accounting matrix (SAM)

A SAM is a square matrix with the rows and columns representing the income and expenditure accounts of various economic agents. The payments (expenditures) are listed in columns and the receipts in rows. As each account must balance, the corresponding row and column totals are equal. There are six types of accounts in the SAM: production activities, commodities, and factors (labour and capital) accounts; the current accounts of the domestic institutions, divided into household, firms, and the government; the capital account and the rest of the world (ROW) account. The SAM is considered to be a consistent data set. It is a matrix presentation of the System of National Accounts in which the linkages between the traditional I-O tables and the institutional accounts are elaborated. It is expected that the SAM can provide a comprehensive and detailed quantified description of the main macro-economic links and financial interrelationships within a country. Figure 1 is an example of a SAM.

3.2 Input-output (I-O) table

An I-O table describes the flow of goods and services between all the individual sectors of a national economy over a stated period of time, say, a year (Leontief, 1986). The I-O table is a subset of the SAM. It consists of activity and commodity accounts only. I-O tables are often used in assessing the impact of a change in the final demand on all

	Wants	Goods & Services	Production	Generation of Income	Allocation of Income	Secondary Distribution of Income	Use of Income	Capital Account	Fixed Capital Formation Account	Financial Account	ROW Current Account	ROW Capital Account
Wants							Priv Con Exp					
Goods & Services	Priv Con Exp	Trade/Transport Margins	Intermediate Consumption				Govt/NPI's F. Consumption	Changes in Inventories	GCFC		Exports	
Production		Output at Basic Prices										
Generation of Income			Net Value at Basic Prices								Comp. of Emp. from ROW	
Allocation of Income		Taxes less Subsidies		Net Generated Income	Property Income						Property Income from ROW	
Secondary Distribut'n of Income					Net National Income	Current Transfer					Current Transfer form ROW	
Use of Income						Net Disposable Income	Adj. Net Equity on Pension Funds					
Capital Account							Net Saving			Borrowing		Capital Transfer from ROW
Fixed Cap Formation			Depreciation					Net fixed Cap. Formation				
Financial Account								Lending				Lending ROW
ROW Current Account		Imports		Comp. of Emp. to ROW	Property Income to ROW	Current Transfer to ROW						
ROW Capital Account										Borrowing ROW	Current External Balance	
Total												

Figure 1.
Social accounting matrix

sectors of the economy. The technique used for this purpose is attributed to Wassily Leontief and is known as the Leontief model. The basic idea of the model is quite simple. The quantity of the output of sector i absorbed by sector j per unit of its total output j is described by the symbol a_{ij} and is called the input coefficient of the product of sector i into sector j. A complete set of input coefficients of all sectors of a given economy arranged in the form of a rectangular table corresponding to the I-O table of the same economy is called the structural matrix of that economy. Although in principle the intersectoral flows, as represented in an I-O table, can be thought of as being measured in physical units, in practice most I-O tables are constructed in value terms. The structural matrices are usually computed from I-O tables described in value terms. In any case, the input coefficients must be interpreted as ratios of two quantities measured in physical units (Leontief, 1986). The I-O table expressed in value terms can be interpreted as a System of National Accounts. Figures 2 and 3 show a typical I-O table.

4. The use of CGE models on forestry policies and deforestation

CGE models have been traditionally applied in studies concerning international trade and taxation. During the last decade, these models have been successfully used in studies evaluating carbon dioxide emissions and carbon taxes. The purpose of this section is to emphasise the capability of CGE models in analysing forestry issues. Table I gives a summary of CGE models used to analyse various issues relating to forestry and deforestation.

A standard CGE model can shed some light on the interaction between forestry and non-forestry sectors. For example, ORANI, a multi-sectoral model (Dixon *et al.*, 1982) can be used to estimate the impact of a range of economic changes on Australia's forestry and wood-based industries as shown by Bruce (1988). However, in models attempting to analyse specific forestry issues such as the stumpage tax, the

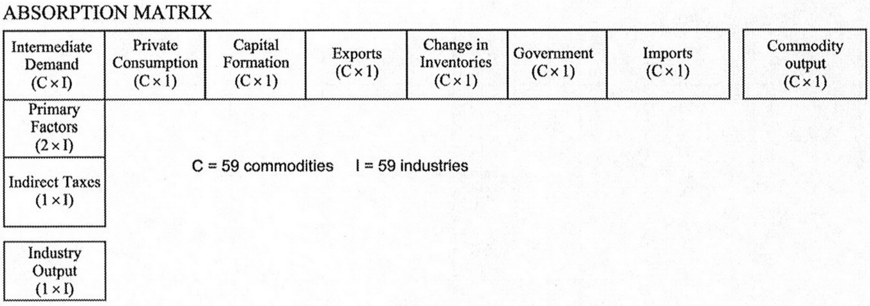

Figure 2.
I-O table, domestic/non-competitive

ABSORPTION MATRIX

	Intermediate Demand	Private Consumption	Capital Formation	Exports	Change in Inventories	Government
IMPORTS	(C × I)	(C × 1)	(C × 1)	0	(C × 1)	0

Figure 3.
I-O table, imports

Table I. CGE models applied to forestry issues

Author(s)	Key features	Demand and production functions	Base year	Main data and key parameters	Policies analysed	Key results
Bruce (1988)	One hundred and thirteen sector static model for Australia	Nested CRESH production function and LES utility function	1980-1981	I-O table parameters from the Industries Assistance Commission	Short-run impact of a range of economic changes on the forestry and wood-based industries	Indirect GE effects can be significant. National employment multipliers of 1.2 and 1.8 for increased woodchip exports and afforestation, respectively
Dee (1991)	Eight sector static/dynamic Johansen model for Indonesia	Nested CES production function and LES utility function	1985	I-O table, SAM	Economic consequences of various forest specific policies (i.e. increase minimum age of trees, reduction in forestry discount rate, establishment of set aside areas and stumpage taxes)	Establishment of set-aside areas would best deal with the problem of deforestation in terms of achieving a set target of timber volume standing after each harvest
Thiele and Wiebelt (1994)	Eleven sector static model for Cameroon	Nested Leontief CES production and LES utility functions	1979-1980	I-O table, SAM	Medium-term effects of alter-native economic policy measures on the forest resource of an economy with tropical rain forest subjected to log harvesting and production	Liberalised trade and low discount rate in forestry (allowing for long-term logging concessions) would help in averting deforestation and increase economic growth

(continued)

Table I.

Author(s)	Key features	Demand and production functions	Base year	Main data and key parameters	Policies analysed	Key results
Persson (1994)	Seven sector dynamic (two-period) model for Costa Rica	Cobb-Douglas utility function Nested CES/Leontief production function	1986	SAM, National Accounts, values of elasticity parameters are set at 0.8 and 0	Effects of lower deforestation rates in the economy and of taxes on factors of production and tradable goods	Temporary tax on capital imposed in period 0 increases deforestation while a temporary subsidy on land has the opposite effect. Taxes on forest, agriculture and industry products do not induce deforestation
Persson and Munasinghe (1995)	Seven sector static model for Costa Rica	Nested CES/Leontief, log-linear, monotonic decreasing production functions	1986	I-O table, National Accounts, values of elasticity parameter are set at 0.5, 0.8 and 0	Effects of government policies on forests in the presence of incomplete markets	High interest rates, taxes on unskilled labour and agricultural products result in deforestation. The rate of deforestation is reduced when property rights are defined
Wiebelt (1995)	Eleven sector static model for Brazil	Nested Leontief, CES and Cobb-Douglas production function Additive nested CES utility function	1980	SAM, I-O table	Effects of macroeconomic policies on forest resources such as currency devaluation, equalisation of tax incentives and land tax reform	Devaluation increases land use and reduces domestic wages. Equalisation of fiscal incentives reduces GDP and overall land use in the Amazon. Economic development is not hampered by a regionally focused program of land taxes in the Amazon

(continued)

Table I.

Author(s)	Key features	Demand and production functions	Base year	Main data and key parameters	Policies analysed	Key results
Alavalapati *et al.* (1997)	Nine sector static regional model for British Columbia	Nested CES production function CRESH for the forestry sectors	1984	I-O table various sources	Investigates the impact of an increase in stumpage fees on the overall economy and on income distribution	Stumpage fees increase results in a significant decline in employment and income. Average households income declines more than the poor house-holds income. Negative economic effects of policy change are higher in the Interior than on the Coast
Thompson *et al.* (1997)	Nine sector static model for British Columbia	Cobb-Douglas production and consumption function	1988-1989	I-O table, parameter values from the Ministry of Finance	Examines changes that may occur in the evaluation of different forest management options when forest values other than timber production are considered explicitly	A 20 per cent land base reduction in current commercially operable forest yields the highest NPVs when either timber and non-timber values remain constant or the discount rate is high (or both)
Cattaneo (2001)	Ten sector static regional model for Brazil	Nested CES production function Cobb-Douglas consumption function	1995-1996	I-O table, SAM, National Accounts and agricultural census	Impact on deforestation of changes in real exchange rate, agricultural tax, transportation costs, land tenure regimes and agricultural technological change	A 40 per cent devaluation in real terms causes, in the long run, a 12 per cent decrease in deforestation. Regulating tenure regimes is the best option to reduce deforestation

implementation of a standard CGE model requires additional variables. For instance, Alavalapati *et al.* (1997) set the stumpage fees as exogenous variables in the model to investigate the impact of an increase in stumpage fees on the overall economy of British Columbia and on the income distribution of two income classes.

Figure 4 shows the possible interaction between forestry and non-forestry sectors in terms of primary factor demands and primary inputs to production. For example, the forestry and agricultural sectors can compete for land as a primary factor to production, as well as mining and the real estate sectors. Whist the wood manufacturing and paper and paper products use forestry products to produce their outputs. The interrelationships of the economic sectors are disclosed fully within a CGE framework depending on the level of disaggregation.

Deforestation is the process of felling trees, which results in the reduction of forest areas. The process of deforestation in each country can vary. Figure 5 is a representation of changing land use. There have been disagreements as to the primary cause of deforestation, that is, either logging or agriculture. The nature of land use

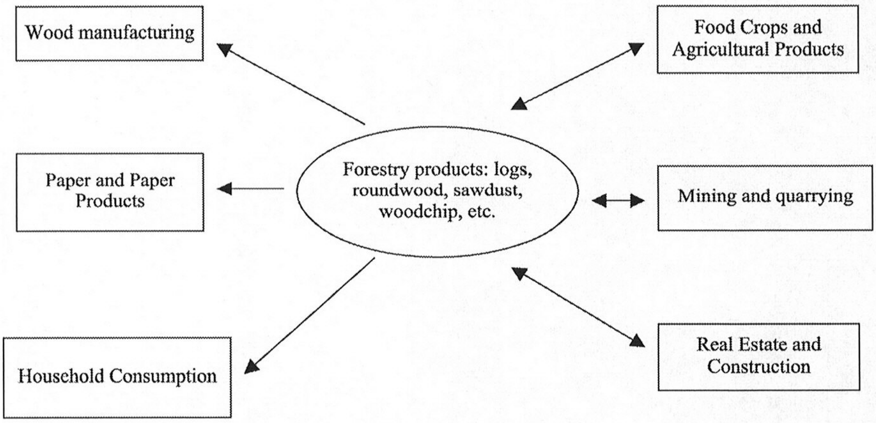

Figure 4.
Example of the interrelationship between sectors

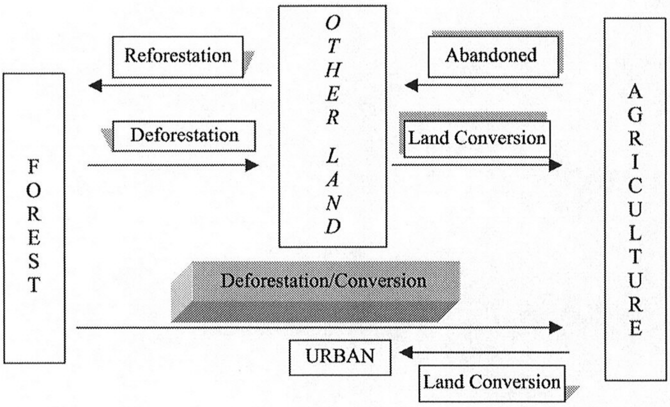

Figure 5.
Overview of national land-use categories

and land conversion in a specific country will determine the sectors and primary factors included within a CGE model. The succeeding discussion highlights this point.

Firstly, in the Brazilian Amazon cattle ranching was identified as the primary cause of deforestation followed by small-scale farming and then logging. In order to incorporate this within a CGE model, Wiebelt (1995) included "livestock" as one of the producing sectors. The model is a static CGE model with regional dimensions. Regional disaggregation can yield significant results when the forest area in question is quite huge like that in British Columbia and in Brazil.

Secondly, in Costa Rica squatting has a significant contribution to deforestation, hence Persson (1994) and Persson and Munasinghe (1995) allowed for a "squatting" sector. The former developed a dynamic (two-period) model with endogenous savings and investment while the latter devised a static CGE model of an open economy. The assumptions of the models are similar. The models differed from the standard CGE model with the inclusion of undefined property rights and the markets for logs and cleared land. It is assumed that squatting was responsible for deforestation to a larger extent compared to logging. It is also assumed that land available for deforestation is unlimited and that the squatting and logging sectors are interdependent on each other. Replanting, as an investment was unattractive since the yield is far into the future. Both studies emphasised property regimes and made use of higher discount rates to reflect insecure property rights.

Lastly, Cattaneo (2001) extended the model by Persson and Munasinghe (1995) to include a feedback mechanism into the deforestation process i.e. land degradation. The study focused on the role of land as a factor of production and considered only land clearing for agricultural purposes as deforestation. In other words, logging by maintaining some forest cover does not contribute to deforestation. This constraint is brought about by the satellite data used in the study.

When it is recognised that logging is the major cause of deforestation, the modelling becomes even more difficult. The modeller's task is to include the concept of sustainable forestry management and forestry rotation periods in a CGE model (Dee, 1991; Thiele and Wiebelt, 1994; Thompson *et al.*, 1997). Wiebelt (1995) managed to avoid (or exclude) the introduction of forestry variables such as the rotation period and harvest level due to the fact that logging in the Brazilian Amazon has generally been a by-product of clearing for agricultural practices, hence the forestry rotation period is irrelevant. Similarly, Persson and Munasinghe (1995) used instead an exogenous parameter, $H(d)$, to represent the opportunity value of the forests, which was set 28 per cent higher than the value derived from deforestation. The authors assumed that the forestry sector exhibits a log-linear production function with decreasing returns to scale.

Thompson *et al.* (1997) constructed a model that requires specific forestry data generated by a timber supply model appended to the CGE model. The timber supply model projects the forest inventory, timber harvest and the outcomes of management practices on inventory and timber yield. Generally, environment-related data, in general and forestry data, in particular, are not readily available especially in LDCs where most of the world's deforestation is occurring. Hence, the forestry sub-model developed by Dee (1991), which was based on the Faustmann formulation requiring eight forestry-specific parameters, offered an attractive alternative to elaborate forestry models.

Thiele and Wiebelt (1994) adopted the Dee model and appended it to their model, which closely followed that of Dervis *et al.* (1982), to evaluate the problem of deforestation in Cameroon. Dee (1991) built on ORANI to assess the problem of deforestation in Indonesia. She intended at first to develop a fully dynamic general equilibrium model with steady-state treatment of the forestry sector. However, the model that was implemented was the static version[7]. The steady-state treatment of forestry was embodied in the forestry sub-model, which was attached to the CGE model. The forestry sub-model included forestry parameters, which differentiated the forestry sector from the non-forestry sector. It incorporated growth functions for forest areas, rotation periods and other forestry specific variables such as minimum harvest age, discount rate in forestry, stumpage tax and set-aside forest areas.

Unfortunately, the models fall short of capturing the dynamic and long-term nature of forest resources. Xie *et al.* (1996) pointed this out as well as the fact that the models are calibrated using one-year data set. The authors also criticised the treatment of land as a factor of production in these models. The model by Cattaneo (2001) is a step closer to refining the treatment of land as a primary factor within the CGE framework. The study differentiated between land conversion (i.e. forested land to arable land and unemployed arable land to pasture) and land transformation (e.g. arable land to pasture). The introduction of different land types is referred to as the bio-physical component of the modelling framework. The author claims that this framework is a first step in linking bio-physical changes to the economic incentive for agents to modify existing land-use patterns.

5. Conclusion

The models reviewed in this paper demonstrate that CGE modelling is increasingly being applied to issues concerning the forestry sector. Most of the CGE models included in this study are static models. The incorporation of dynamic equations in capital formation will improve the usefulness of these models.

The assumption of steady-state in forestry growth and the use of the steady-state equations in the modelling of the forestry sector (Dee, 1991; Thiele and Wiebelt, 1994) are somehow unrealistic especially in relation to forests in developing countries, which are not always in steady-state. One justification is that over time the constant application of sustainable management in forestry and increased intensity of reforestation activities will steer forest growth towards a *steady-state* level of production.

One alternative to the steady-state treatment of forestry in CGE models is the inclusion of a reforestation variable. This would greatly improve the valuation of environmental concerns in CGE models. This can be achieved by the development of a SAM or at least an I-O table with a reforestation sector.

In sum, the use of CGE models in analysing forestry issues is still in its early stages. There is room for innovation and improvement in the various models used. At present, the cost of forest conservation within a CGE model is measured in terms of the reduction in GDP. Nevertheless, the significance of forestry policies and its effects on the rest of the economy are highlighted in results generated by environmental CGE models.

Notes

1. The main difference between static and dynamic models is in the treatment of investment.
2. Sensitivity analysis answers the question as to how the optimal choice variables change as the value of a parameter changes (Varian, 1992, p. 491).
3. For example, Alavalapati *et al.* (1997) used real income as an indicator of welfare instead of real consumption.
4. The set of initial values for prices, quantities, etc. is known from the I-O data.
5. We assumed that $A(Z) = A(Z_y, Z_x)$. Similarly, $F(Z) = F(Z_y, Z_x)$.
6. If this is not true, then the Johansen method will fail (Dixon *et al.*, 1982, p. 235). If the inverse of the matrix is singular, then it is likely that the classification of exogenous and endogenous variables is illegitimate.
7. All the dynamic equations are turned off hence, converting the model into a static CGE model. The steady-state treatment of the forestry sector is maintained.

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