An Econometric Model of Tropical Deforestation

Shashi Kant and Anke Redantz*

Abstract

A cross-sectional econometric model of tropical deforestation has been developed. Causes of tropical deforestation have been classified into two levels. The first-level (or direct) causes are grouped into two classes, i.e., pressure for forest products (for consumption and exports) and pressure on forest land for alternative (cropland and pasture) land uses. The most discussed causes of deforestation such as population, gross domestic product, external debt, government policies etc., are placed into second-level causes. The model, for a data set of 65 countries (35 African, 13 Asian, and 17 Latin American), is estimated in two stages by the heteroscedastic-consistent maximum- likelihood estimation procedure. In the first stage, the first-level causes are regressed on the second-level causes, and in the second stage, deforestation is regressed on the estimated first-level causes from the first stage. The model addresses three econometric issues i.e., the distinction between the first-level (direct) and the second-level (indirect) causes, the possibility of difference in the coefficients of explanatory variables across the geographic regions, and the problem of heteroscedasticity. The results of the estimated model are discussed in terms of the effect of different direct and indirect causes on deforestation in three geographic regions. On the basis of the elasticity of deforestation with respect to different first and second-level causes, some possible policy interventions in selected countries are also discussed.

Keywords: Heteroscedastic-consistent estimation, maximum-likelihood estimation, point elasticity, policy issues, two-stage estimation.

~

Introduction

Forests are valuable environmental and economic resources which support natural systems and play an important role in the economic welfare of human societies. They maintain the dynamic conditions necessary for their own continued existence and support other ecosystems within the natural system. For example, they are at core of the local and global hydrological and carbon cycles.

* Shashi Kant, Faculty of Forestry, University of Toronto, 33 Willcocks Street, Toronto, Ontario, Canada. M5S 3B3. E-mail: kant@foreco.forestry.utoronto.ca
Anke Redantz, Agricultural Economics Department for Tropical and Subtropical Agriculture, University of Hohenheim, Stuttgart-Hohenheim, Germany.

Forests are home of a large proportion of the earth's biodiversity which is valued for utilitarian, aesthetic, moral, and ecological purposes (Sharma, 1992). The natural amenities provided by forests are a great asset for the quality of human life. Due to these various important roles, threats to the world's forests are evoking responses at all levels, from villagers organising to manage their forests to international summit meetings of world leaders. Forest losses and the many threats from multinational companies, large scale development projects, atmospheric pollution, peasant-farmers, fuel-gatherers, and ranchers have been widely documented (Repetto, 1988).

In recent years, numerous observers including foresters, environmentalists, economists, and other social scientists, have voiced concern over the destruction of tropical forests (Sharma, 1992; Bundestag, 1990). A number of descriptive and theoretical attempts have been made to analyze or understand the phenomenon of deforestation, especially in developing/tropical countries (Bowonder, 1982; Bajracharya, 1983; World Resource Institute, 1985; Walker, 1987; Richard & Tucker, 1988; Winterbottom, 1990; Barbier, *et al*., 1991; Binswanger, 1991; Larson & Bromley, 1991; World Bank, 1991; Sandler, 1993). Pearce & Brown (1994) summarise diversity of causes of deforestation argued by researchers. These efforts notwithstanding, there is much disagreement on the magnitude, causes, and consequences of deforestation (Fearnside, 1982; Lugo & Brown, 1982; Myers, 1994). Palo (1994) observes:

> *"Demographers, geographers, economists, sociologists, and scientists from some other disciplines have traditionally been engaged in research concerning the relationships of population pressure with economic development, environment, and deforestation. No interdisciplinary consensus has so far been reached...."*

It reflects the great difficulties confronting any attempt to come to a general understanding of the main factors underlying the processes of deforestation.

Resource economists and some other social scientists have attempted to probe those processes with the help of statistical and econometric techniques. These have varied greatly in scope, in quality of data used, and in adequacy of statistical tools and methodology. Some econometrically sound studies have been undertaken at the national level (Southgate *et al.*, 1991; Kummer, 1992; Reis & Guzman, 1994; Panayotou & Sungsuwan, 1994). Some authors have even attempted a dynamic systems approach at the national level (Saxena & Nautiyal, 1996). But Kummer & Sham (1994) emphasise the negligible role played to date by cross-section global studies in throwing light on these issues. In principle, they should be an important complement (rather than a substitute) for national studies. Each has advantages over the other in what it can elucidate. Global (cross-country) studies are very important to understand the phenomenon of deforestation at the regional or global level. But most such studies undertaken to date suffer too many econometric problems to lend their results much credibility; methodological issues have not been addressed adequately.[1] Though data limitations and unavoidable econometric complications will always make such studies difficult and challenging, and perhaps less sound than the national studies, there is definitely a scope to improve such global studies from the present level.

In this paper, an attempt has been made to address some of the neglected methodological/econometric issues. A two-stage recursive econometric model for tropical deforestation is proposed and estimated with the help of the most recent data of deforestation available from FAO 1993. The causes or determinants of deforestation are categorised into two levels — direct (proximate) and indirect (underlying). The rate of deforestation is expressed as a function of (regressed on) the direct (first-level) causes; each of these has previously been expressed as a function of the indirect (second-level) causes.

---

[1] Reis & Guzman (1994) point out some very specific weaknesses of deforestation studies:

"Econometric results on elasticities of deforestation are scanty. Table 12.2 provides an incomplete survey of them, which shows major differences of specification, sampling variables, geographic aggregation, and measurement of data. Furthermore, in most cases, parameters were not explicitly derived from theoretical models, thus making comparisons even more difficult. Note also that equations are under-estimated."

Kummer & Chi Ho Sham (1994) also observes:
"However, we should argue below that the results are fundamentally flawed and the role of population overstated. The two major problems with the studies enumerated above is that four use an inappropriate dependent variable and the other three are based on data sets which are of doubtful validity."

To put the analysis in perspective, the literature regarding the deforestation is first reviewed, and unaddressed econometric issues are summarised. Thereafter, a theoretical model of deforestation is presented and the sources of data to estimate the proposed model are enumerated. The detailed methodology for estimating the proposed model is discussed. Finally, the results are presented and important policy issues are highlighted.

LITERATURE REVIEW

The intent of this paper is to advance the level of cross-section econometric studies of tropical deforestation; this review of the literature is accordingly limited mainly to such studies and highly selective in its references to the rest of the very extensive literature on tropical deforestation.

Time-series analysis of deforestation at either the regional or the global level is almost impossible due to the lack of data. Therefore, time-series studies are mainly limited to the country level (Lombardini, 1994; Chakraborty, 1994). To analyze the process of deforestation over time, some authors have attempted panel analyses at the global level (Capistrano, 1994) or at the country level (Kummer & Sham, 1994). In some national studies, the authors have pooled the cross-section and panel data (Constantino & Ingram, 1990; Osgood, 1994).

Global-level analyses are dominated by cross-sectional studies. Some cross-sectional studies use total forested area or forested area/total area as a dependent variable (Lugo *et al.,* 1981; Palo, 1987). Current forest reflects the original forest cover and the forest cover lost. Hence, it is the result of a process which can date back anywhere from a few years or decades to several hundred or thousand years. This longer-run process, however, is not captured by the just-cited variable. Hence, the use of forest area as a measure of deforestation does not seem appropriate (Kummer & Sham, 1994). Other cross-section studies use deforestation as the dependent variable (Allen & Barnes, 1985; Rudel, 1989; Kahn & McDonald, 1994; Capistrano, 1994; Shafik, 1994). Though some measures reflecting the rate of deforestation is an appropriate choice, a number of important econometric issues are not adequately dealt with in these studies.

First, the distinction among direct and indirect explanatory variables, though utilized in some of the national studies (Southgate *et al*., 1991; Saxena & Nautiyal 1996), has not yet been made in the global studies. For example, the effects of agriculture-land/cropland and population on deforestation are estimated simultaneously (as a part of the same equation), even though population is an obvious causal factor in the change in cropland. Similarly, the effects of Gross Domestic Product (*GDP*) level or growth are estimated together with those of change in cropland, though they help to explain variation in the amount of cropland.

Second, although some studies have tried to capture differences among regions by using regional dummies to reflect differences across the regions in the intercept (constant) of the regression, none has yet attempted to capture quantitative differences in the effects of independent variables (slopes of the dependent variable with respect to those variables) across regions. In the global studies, the possibility that some explanatory variable may be applicable to only a particular region, or be more important in some regions than in others, has thus been ignored.

Third, only a few studies have addressed the problem of heteroscedasticity, common in cross-section studies, and even these have not tended to deal with it adequately. Hence, a study which addresses these three issues may be able to provide some deeper insights into the processes of global deforestation.

THEORETICAL MODEL

A fundamental feature of deforestation is that the causal factors of deforestation are linked together as various chains or mechanisms into a causal system (Palo, 1994), and the different factors responsible for deforestation work at different levels. Hence, deforestation is the result of a complex process, and a simplistic approach to seek " causes" is not enough. Rowe *et al*., (1992) and Grainger (1993, p.17–18) divided the causes of deforestation into direct and underlying causes. To keep our model within manageable limits, we also restrict to two levels of causes, i.e., direct (first-level) and indirect (second-level). Rowe *et al*., (1992) identified fuelwood gathering, commercial

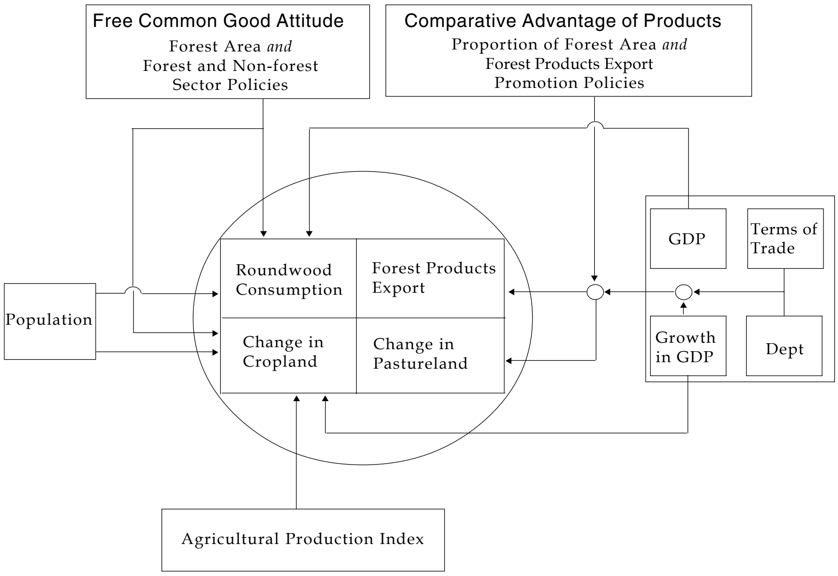

FIGURE 1. INTERACTIONS BETWEEN DIRECT AND INDIRECT CAUSES OF DEFORESTATION

logging, infrastructure and industrial development, agricultural expansion, and overgrazing as the main direct causes. The first three causes are the result of increased demand of forest products and the last two of the increased demand of forest land for alternative land use. Hence, all the first- level (direct) causes can be grouped into these two categories: the demand of forest products and the demand of forest land for alternate land use. The demand of forest products will arise from domestic consumption and exports of forest products, and the demand of forest land for alternate land use comes in terms of demand of cropland and pasture. There is some other minor demand of forest land for development projects such as road or dam construction. But due to the non-availability of land conversion data for these purposes or any other measure of this demand at the global level, we restrict our model to only two factors, i.e., cropland and pasture; and assume that the minor demands of other land uses will be either picked up by the selected variables or will be left as a residual in error term. Consequently, we have chosen the first-level (direct) causes of deforestation as roundwood consumption, export of forest products, change in cropland, and change in pasture land.[2]

An analysis of deforestation with the help of the first-level variables alone cannot capture all (or perhaps very much) of the causal processes in which we are interested. Understanding the linkages between the first- level (direct) causes and the second-level (indirect) ones is also essential. The interactions between the first-level and the second-level causes are shown in Figure 1.

The simplest way of taking both levels into account is to explain deforestation through a system of five recursive equations.[3] The first equation describes the relationship between the amount of deforestation as a dependent variable and the four first-level causal factors as independent variables. The equation can be expressed as:

$$Y_1 = \alpha_1 + \boldsymbol{\beta}_1'\mathbf{X_1} + U_1, \tag{1}$$

where Y_1 is deforestation, $\mathbf{X}_1$ is a vector of the four first-level causal factors, i.e., roundwood consumption, export of forest products, annual change in cropland, and annual change in pasture, and U_1 is an error term. α_1 represents the intercept and $\boldsymbol{\beta}_1'$ is a row vector of the slope coefficients corresponding to the four explanatory variables.

[2] It may be argued that there are only two categories of first level causes, i.e., the demand of forest products and the demand of forest land, and hence roundwood consumption and forest products exports should be clubbed together and similarly the cropland and pasture. However, the major portion of roundwood consumption and export is met by regular harvesting and only remaining part through deforestation. The contribution of deforestation to roundwood consumption and export need not to be the same. Combining roundwood consumption and export would restrict the coefficients of the two components to be the same that would mean the same contribution of deforestation to roundwood consumption and exports. Same will be the result of combining cropland and pasture into a single variable. Hence, combining the two different components of either forest products or forest land will not be theoretically desirable.

[3] This approach is still too simple but definitely more sophisticated than the approaches available in the existing literature of tropical deforestation. The limitations of the approach are: first, an assumption that the first level causes are independent of each other; and second, the model has been limited to only two levels while the variables at the second level are not totally independent variables, and they are also driven by some other independent variables at the further lower levels. However, incorporation of these complexities may not provide enough additional information as compared to the level of difficulties involved in. Hence, we restrict to this approach. Please also refer to footnote 12.

All the four explanatory variables in this equation are determined by the second-level (indirect) causes of deforestation, and, hence, are endogenous to the system. The four other equations establish the relationships between the four first-level causes and the underlying, second-level, causes. Each of these equations is now discussed in turn.

Roundwood Consumption Equation

According to consumer theory, the main determinants of individual's consumption are his income level and the price of a good. The aggregate national consumption will depend upon the national income or the gross domestic product (*GDP*).[4] Due to non-availability of price (for the same forest product in the same year across the countries), the price variable is problematic in cross-sectional studies. The basic physical features of forest, i.e., vastness and the unbounded nature, create an impression of forest as a free common good for everyone. This perception of the people is enhanced by the government policies. In most of the countries, the prices of forest products are distorted by the forest-sector and allied sector policies. Number of forest-sector policies of tropical countries, such as timber concessions, low royalties and license fees, insecure tenure policies, and incentives for wood processing industries encourage the undervaluation of the resource by the general public. In many countries, the policies outside the forest-sector such as: (*i*) agricultural programs under which land is cleared for estate crops like rubber, palm oil etc., (*ii*) tax, credit, and pricing policies that stimulate private investment in competing land uses, and (*iii*) transmigration policies also encourage the undervaluation of the forest (Repetto, 1988, pp.17–31). Hence, in tropical countries, the physical nature of forest and government policies lead to 'Free Common Good Attitude' (*FCGA*) towards forests. The degree of this attitude reflects peoples' perception about the extent of the forest area, which depends in turn on the actual forest area and government

[4] The use of transitory real disposable income could have been more appropriate than the use of *GDP*, but the data availability restricted us to use *GDP*. The incorporation of some other variables like employment level and wealth effect can also be argued. However, due to data limitations and simplicity of model, we restricted to the two basic economic factors, i.e., income and price, and one demographic (population) factor.

policies. The *FCGA* will influence the roundwood consumption, stronger is the *FCGA* higher will be the consumption. Due to the lack of any uniform quantifiable measure of government policies over the tropical world, we use the absolute forest area as a measure of *FCGA*.[5] The *FCGA*, and hence the total forest area is a proxy for the price variable. The total forest area has been used by many researchers (Kahn & McDonald, 1994; Rudel, 1994) as an explanatory variable but these intricacies are not elaborated.

The most commonly used other explanatory variable of deforestation is population (Kahn & McDonald, 1994; Capistrano, 1994); and obviously it is argued that higher the population higher will be deforestation. Since, we are estimating deforestation in two stages, population will be explanatory variable of some second-level causes. The roundwood consumption will definitely be one of those.[6]

The coefficients of all the three explanatory variables will be positive, and the roundwood consumption equation can be expressed as:

$$X_2 = \alpha_2 + \boldsymbol{\beta}_2' \mathbf{Z_2} + U_2, \tag{2}$$

where X_2 is roundwood consumption, $\mathbf{Z_2}$ is a vector of the absolute forest area, *GDP*, and population, U_2 is an error term, and α_2 and $\boldsymbol{\beta}_2'$ represent intercept and a row vector of slope coefficients, respectively.

---

[5] The coefficient of the absolute forest area will not capture the total effect of *FCGA*. But, due to the absence of any other appropriate measure either for government policies alone or a combined measure of the *FCGA*, we us the absolute forest area as a measure of the *FCGA*. Larger absolute forest area will reflect higher *FCGA* and lower prices, and hence more deforestation.

[6] The population structure (population in the different income groups) may be a better explanatory variable than the total population, but again due to the limitations of data and the simplicity of the model, the choice is restricted to the total population.

The use of *GDP* and population together is also debatable; and one may argue to use *GDP* per capita and population. But, the roundwood consumption is composed of consumption by individuals or households and industrial and infra-structural consumption. The *GDP* per capita is more appropriate to capture the household consumption while the *GDP* seems more appropriate to capture industrial and infra-structural consumption. However, the use of both *GDP* and *GDP* per capita seems irrational and it will also create multicollinearity problem. In fact, the statistical estimates by using *GDP* per capita and population were theoretically inconsistent. Hence, *GDP* and population are preferred.

Forest Products Exports Equation

In the case of developing countries, the exports of primary products like agricultural products, forest products, and minerals etc., serve as an engine of growth (Gillis *et al.*, 1992, p. 419). The fundamental economic theory of international trade is the theory of comparative advantage. However, six classes of assumptions (two dimensionality, perfect mobility, perfect competition, similarity in factor endowments, technology, and demand) are used to produce trade theory's sharpest results (Leamer, 1987, p.2). In real life, none of these assumptions is observed. But, the concept of comparative advantage can be used to get some insights of forest products trade. The total exports from a country consist of many products, and the quantity of export of a product will depend upon the comparative advantage of the product over other products. In the case of developing countries, the major portion of the exports comes from the primary products, and most of these products are land based. Hence, the 'Comparative Advantage of Forest Products' (*CAFP*) with respect to other products can be measured by the forest area as a percentage of the total land area.[7]

The most discussed explanatory variable of deforestation is debt. Many hypothesi have been offered for linkages between deforestation and debt such as myopic behaviour (Kahn & McDonald, 1992) and real currency devaluations (Capistrano & Kiker, 1990). But, whatever may be the actual relationship between debt and deforestation, debt will always work through the trade of forest products. In the present context, when almost all the countries have substantial external debt, the total debt must be one of the most important variables affecting the tendencies of tropical countries for the exports of forest products.

The other explanatory variable of export will be the export price. But in the case of exports from one country to many countries, it is very difficult to specify one export price of forest products for each country. However, the

1 Similar to the concept of *FCGA*, introduced in the roundwood consumption section, the *CAFP* will depend upon the percentage forest area as well as on forest products export promotion policies of national governments. But, due to the limitations on the measurement of these policies, the percentage forest area has been selected to represent *CAFP*.

terms of trade (*TOT*), which is a ratio of the average price of a country's exports and the average price of country's imports, represents the competitiveness of a country in the international trade; and it seems to be appropriate to select it as a proxy of export price.[8] The sign of *TOT* can be argued to be positive if looked from supply side and negative from demand side. The export quantities being the figures of actual exports which means that these quantities represent the demand faced by the exporting country. Hence, the negative sign seems more reasonable. The significance of an increase in *TOT* would also normally be a more favourable balance of payment situation, a more expensive currency, and hence less exports. Therefore, these two factors, i.e., demand of exports and balance of payment situation would lead to a negative sign of *TOT* coefficient.

Another explanatory variable of exports comes from the growth of an economy. The interaction between exports and growth rate is quite interesting. First, exports are used to accelerate the growth of an economy. But, once economy starts growing, the increasing growth rate works as a catalyst to exports. Hence, over a period of decade the causal relationship between the two becomes confusing, and it would lead to a problem of simultaneity among these two variables. This problem cannot be sorted out in the cross-sectional studies (it can be in time-series studies). In our study, the rate of growth data is an average over a decade (1980–89) and the export data is a single year (towards the end of decade 1988) data, and we are assuming that the increased annual growth rate leads to an increase in exports on an average. Hence, the coefficient of the growth rate should be positive.

With the explanation of these four explanatory variables, the forest products exports equation can be expressed as:

$$X_3 = \alpha_3 + \boldsymbol{\beta}_3' \mathbf{Z}_3 + U_3, \tag{3}$$

where X_3 is the export of forest products, $\mathbf{Z_3}$ is a vector of the forest area as a percentage of total land area, the total external debt, the terms of trade, and the growth rate of

[8] The terms of trade of only forest products will be a better proxy of the export price of forest products. But due to data limitations, we are forced to select the overall terms of trade as a proxy of the export prices.

GDP, U_3 is an error term, and α_3 and $\boldsymbol{\beta}'_3$ represent intercept and row vector of slope coefficients, respectively.

Cropland Equation

For the majority of tropical countries, the agriculture sector is one of the key sectors of the economy. The agriculture sector contributes to the economy in terms of contribution to *GDP*, employment and exports (Torsten, 1992, p. 51). The agriculture production index is one of the key independent variables itself to explain the variation in crop land.[9] As a result of the population growth, land reserves in many developing countries have been declining (Scholz, 1988, quoted in Torsten, 1992, p. 53). The growing scarcity of cropland has caused an expansion of the cropland into tropical forest areas. The different activities of the agriculture sector contribute to the conversion of forest land to cropland. On one hand, due to increased population pressure on the existing cropland, people migrated to tropical forest areas and resort to shifting cultivation. These shifting cultivators partly belong to the subsistence sector or are integrated into local and regional markets (Torsten, 1992, p. 53). On the other hand, forest land conversion is caused by permanent and sedentary agriculture. These big farmers are usually integrated into national or international markets, and many of them produce agriculture products for exports. Hence, in some countries, the expansion of the agricultural sector into tropical forest areas is mainly due to export crops (Torsten, 1992, p. 53). Therefore, two resulting factors of cropland expansion into forest areas are population and the rate of growth of *GDP*.[10] In addition to these three factors, the conver-

[9] In many countries the information on yields is partial or that on land is partial, and one tends to be calculated as a function of the other. It may tend to impart an upward bias to the relationship between area and output, and part of the explanatory power may be spurious. But, it is natural that the production index will be the key independent variable. One may also question the problem of simultaneity among these two variables, but again due to aggregation of data almost over a decade, we have overlooked this problem.

[10] The rate of growth of *GDP* is chosen as an explanatory variable to capture the effect of exports of agricultural products. The logic and problems associated with this choice are the same as in the case of the choice of the growth rate of *GDP* in forest products exports. The choice of other variables used in the forest products exports equation like total debt and *TOT* to capture the effect of exports of agricultural products does not give theoretically consistent results.

sion of forest to cropland will also depend upon the supply of forest land that will be determined by the attitude of the people towards forest. In the tropical countries, as argued in the roundwood consumption equation, people have free common good attitude (*FCGA*) towards forest. Hence, *FCGA* measured by the absolute forest area will be the fourth explanatory variable of the cropland equation. The sign of coefficients of all the four variables should be positive. Now, the annual change in cropland equation can be expressed as:

$$X_4 = \alpha_4 + \boldsymbol{\beta}_4' \mathbf{Z}_4 + U_4, \tag{4}$$

where X_4 is the annual change in cropland, $\mathbf{Z_4}$ is a vector of absolute forest area, agriculture production index, growth rate of the *GDP*, and population, U_4 is an error term, and α_4 and $\boldsymbol{\beta}_4'$ represent intercept and row vector of slope coefficients, respectively.

Pasture Equation

Finally, the change in pasture has an interesting mechanism. One may intend to draw a parallelism among the cropland and pasture, but the conversion of forest land to pasture is based on entirely a different mechanism than the conversion to cropland. An overview of the data indicates that the increase in pasture is concentrated in the Latin American countries. In these countries, the increase in pasture is driven by the large scale cattle ranching operations that are the result of heavy emphasis on meat exports (Jepma, 1995). Hence, the conversion of forest land to pasture is parallel to the process of forest products export rather than the process of forest land conversion to cropland. Hence, the explanatory variables for the change in pasture in Latin America will be same as the explanatory variables of forest products exports, i.e., the growth rate of *GDP*, the total external debt, the terms of trade, and the percentage of total land under forest. Therefore, the change in pasture land equation can be expressed as:

$$X_5 = \alpha_5 + \boldsymbol{\beta}_5' \mathbf{Z}_5 + U_5, \tag{5}$$

where X_5 is the change in pasture, $\mathbf{Z_5}$ is a vector of the growth rate of *GDP*, total external debt, terms of trade, and the percentage of total land under forest, U_5 is an error term, and α_5 and β'_5 represent intercept and row vector of slope coefficients, respectively.

These five equations capture all the causal relationships represented in Figure 1, and indicate that there does not exist a simple and direct relationship of deforestation with either the demographic factor i.e., population, or some macro-economic factors like debt or growth rate of *GDP* as modelled by the previous researchers. These factors do influence deforestation, but not directly. One interesting feature of the causal relationship is that the *FCGA* influences deforestation through two different mechanisms, i.e., via roundwood consumption and the change in cropland. Similarly, population influences deforestation through round-wood consumption as well as the change in cropland. *GDP* or the growth in *GDP* also influence deforestation through all the four first-level causes.

DATA AND ITS SOURCES

The reliability of data, particularly of deforestation data, has been a common problem of all the studies of deforestation. Our data source for deforestation data is the FAO Tropical Forest Resources Assessment 1990 (FAO, 1993). This source is said to give a fairly good, and probably the best ever, description of the present forest area and of the changes in forest area between 1980 and 1990 (Jantz, 1993). Nevertheless, the reliability of even this source is questionable, and the results of this study should be used cautiously.

Our sample consists of 65 countries which comprised 35 African, 13 Asian, and 17 Latin American countries. The explanation, units of measurement, and sources of all the variables are given in Table 1.

METHODOLOGY OF ESTIMATION

Econometric models are to be used but not believed in and the best models are not explanatory or realistic, but parsimonious, plausible, and informative (Theil, 1971, preface; Feldstein, 1982). Kennedy (1992, p. 73) even went to say that all econometric models are wrong but some are use-

TABLE 1: DETAILS OF THE DATA USED FOR THE ESTIMATION OF DEFORESTATION MODEL.

SECTOR	VARIABLE	EXPLANATION	UNITS	SOURCE
Forest	*DEFAR*	Annual average deforestation 1981–90	'000 hectares	FAO, 1993
	ABFORAR	Absolute forest area (1980–85)	'000 hectares	Sharma, 1992
	PRFORAR	% of Forest area (1980–85)	Percent	Sharma, 1992
	RWCONS	Annual roundwood consumption 1988	'000 cubic metres	Sharma, 1992
	FOPREXP	Forest product exports 1988	million US$	Sharma, 1992
Agriculture	*CHCROPL*	Annual change in cropland in 1980's	'000 hectares	WRI, 1992
	AGRPRI	Index of agriculture production,1988–90	Base years 1979-81	WRI, 1992
	CHPAST	Annual change in pasture, 1975–87	'000 hectares	Sharma, 1992
Macro-economic	*TOTGDP*	Total GDP 1988	billion US$	UNDP, 1990
	GDPG	Annual growth rate in GDP 1980–89	Percent	Sharma, 1992
	DEBT	Total external debt, 1988	Million US$	WRI, 1992
	TOT	Terms of trade, 1988	Base year 1980	UNDP, 1990
Demographic	*POP*	Total population, 1989	Millions	Sharma, 1992
Regional Dummy Variables	*DUMLAMER*	Latin American Countries		
	DUMASIA	Asia		
	D*UMAFRIC*	Africa		

ful. The process of developing a regression model is directed towards generating a best unbiased estimate for each parameter in the system. But because of inherent errors in measurement of economic variables, almost all the estimators are inherently biased. Hence, we intend to develop a model which is more informative and useful than the models already present in the literature, but our intention is not to achieve something impossible, that is a true unbiased explanatory model of deforestation. Our main focus is on addressing the three econometric issues raised in the section on literature review.

Regression analysis is a process of establishing the cause and effect relationship. Hence, a correct specification of a regression model should capture the real cause and effect relationships. In a correctly specified econometric model, both cause (underlying causes) and effect (direct causes) cannot be used together as explanatory variables of deforestation, and putting the direct and underlying causes together will mean econometric mis-specification of the model. Hence, a system of five recursive equations has been suggested in the theoretical model section. In the specified recursive equation system, the dependent variables of the equations of direct causes (the equations of consumption, export, cropland, and pasture) are endogenous variables, and only the explanatory variables (which are indirect causes) of these equations are exogenous. A standard econometric technique to estimate such a system of equations is the two-stage estimation method,[11] and the proposed model has been estimated by this standard method. In the first stage, four equations (Equations 2, 3 , 4 and 5) of the first- level (direct) causes roundwood consumption, export of forest products, the change in cropland, and the change in pasture are estimated. In the second stage, using the estimated values of these four endogenous variables (direct causes) the deforestation equation (Equation 1) is estimated. The estimation is based on the important assumption that is $\mathrm{cov}(U_1, U_i) = 0$ (where i =2,3,4, and 5). It means that the Equation 1 is not linked to the four equations (2,3,4, and 5) by a correlation between the omitted variables.

The variations in the slopes (coefficients) of different explanatory variables across the regions can be captured by using the explanatory variables corresponding to each region. The separate explanatory variables for each region can be generated with the help of the global variables and regional dummy variables. From the global variable of population (*POP*), for instance, three different regional variables of population are generated by multiplying *POP* with the respective dummy variable.

[11] In the two-stage method, in the first stage, each endogenous variable is estimated by regressing it on the theoretically appropriate exogenous variables, and these estimated values are used as the instrument variables of these endogenous variables. In the second stage, these instrument variables are used to regress the final endogenous variable (Pindyck & Rubinfeld, 1991).

Therefore, $POP \times DUMLAMER$, $POP \times DUMASIA$, and $POP \times DUMAFRIC$ will represent the Latin American, the Asian, and the African populations, respectively. Hence, if population in the three regions has different effects on roundwood consumption, the coefficients of these three variables will be different, and the use of the three variables instead of only one global variable for population will improve the explanatory power of the regression. On the other hand, if population is an explanatory variable of roundwood consumption in only one region, the exclusion of population of the other two regions will also improve the explanatory power of the regression. Similarly, if the effect of population in all the three regions is not significantly different, the use of only one global population as an explanatory variable will give the highest explanatory power to the regression. If the effect of population is similar in two regions but different in the third region, the global population variable and the population variable of the third region will pick up all effect. In this case, the coefficient of global population will give the global effect on all the three regions, and the coefficient of the third region's population will give the difference in the third region from the global effect. This approach of capturing the variation in the coefficients of different explanatory variables across the regions is used for all the five equations and for all the explanatory variables.

In the beginning, for each explanatory variable three different regional variables are used in the estimation of each equation. Based on the outcome, an appropriate combination of the variables is selected that has the maximum explanatory power of the regression and theoretically consistent signs of all the explanatory variables.

To begin with, all the four equations (Equations 2, 3, 4, and 5) of the endogenous variables are estimated by the Ordinary Least Square (OLS) method. In a cross-sectional analysis, there is a high probability of error terms being heteroscedastic. In the presence of heteroscedasticity, the OLS estimates are unbiased and consistent, but inefficient. This inefficiency causes the low t-values. In the OLS estimates of all the four equations (Equation 2, 3, 4, and 5), the signs of all the variables are as expected but the t-values are low. The low t-values may be due to multicollinearity and/or heteroscedasticity. The estimated equations are checked for multi-collinearity and heteroscedasticity, and heteroscedasticity is found in all the four equations. First, heteroscedasticity is corrected by the White method. The signs of all the variables in the OLS estimates after heteroscedasticity correction are as expected, and the t-values improved, but in most cases they did not become significant. For a model with heteroscedastic error disturbance, it is assumed that each error term is normally distributed. This assumption is also necessary for using the maximum-likelihood estimation (MLE) procedure. The maximum-likelihood estimates are asymptotically efficient (Pindyck & Rubinfeld, 1991, p.239). Hence, finally, the heteroscedasticity-consistent maximum-likelihood method is used to estimate all the four equations of the endogenous variables.[12] The same procedure is followed for estimating the deforestation equation (Equation 1). The heterosce-dasticity-consistent maximum-likelihood method improved the t-values to a great extent.

The results of all other procedures except the final results of MLE will not provide other useful information. Hence, it does not seem necessary to discuss all the results, and only the final results based on the heteroscedastic-consistent estimates by the maximum-likelihood method are discussed. This method is based on the concept of loss function, a concept different than that of OLS. Therefore, the MLE gives only R^2 between the observed and estimated values instead of R^2 and adjusted R^2 available in the case of OLS. The values of R^2 between the observed and estimated values are given with the estimates of each equation.

RESULTS AND DISCUSSION

The signs of the coefficients of all the variables in all five equations are as expected, and all the coefficients are different from zero at 1 percent significance level. The Durbin-Watson statistics indicates that the first-order auto-correlation is not a problem in any of the equations. The results of all the five equations are presented next in terms of the estimated coefficients, t-values, the standardised coefficients, and the elasticity at mean values, and discussed.

[12] The five equations are estimated as a system of recursive equations. Alternatively, these equations can be estimated simultaneously. But the software (SHAZAM) used does not provide the facility of simultaneous estimation by heteroscedastic consistent MLE procedure.

Table 2. Estimated Coefficients of Roundwood Consumption Equation.

Variable	Coefficient	T-value	Standardised Coefficient	Elasticity at Mean
ABFORAR	0.313	16.20	0.44	0.39
TOTGDP	127.340	2.83	0.14	0.12
POP	264.000	6.01	0.58	0.43
POP3	350.840	6.28	0.12	0.12
DUMASIA	12704.000	10.21		
DUMAFRIC	3537.400	10.82		
CONSTANT	−5740.000	17.75		

R^2 between observed and predicted values = 0.92.

The suffix of 1, 2, or 3 of the symbol of an explanatory variable indicates whether this variable correspond to Latin America, Asia, and Africa, respectively. These variables are obtained by multiplying the global variable with the dummy variable of the respective region. For example, *POP3* represents population of the African countries, and it is equal to *POP* × *DUMAFRIC*.

This procedure of notations is used in all the tables and discussion.

Roundwood Consumption

The results are given in Table 2. The effect of population on roundwood consumption is different in Africa than in Asia and Latin America, while that of *GDP* and of forest area (*ABFORAR*) or *FCGA* is the same over all the regions. The coefficients of the same variable, for example population, over three different regions can be compared, but the comparison of the coefficients of different variables will not provide any useful information. However, the comparison can be done by looking at the standardised coefficients or at the elasticities, but the interpretation of this comparison should be done within the framework of these measures. Standardised coefficients indicate the change in the dependent variable in terms of standard deviation with respect to a change in the independent variable in terms of standard deviation, while the elasticity gives the percentage change in the dependent variable with respect to a 1% change in the independent variable. Hence, it is not necessary that these two measures will rank all the explanatory variables in the same order. Since the standardised coefficient of an independent variable is subject to the standard deviation of the dependent and the concerned independent variable, which are normally not known to the reader, the elasticity measure is practically more useful.

The results give the coefficients of the population variable to be 264.00, 264.00, and 614.84 (264+350.84) for Latin America, Asia, and Africa, respectively, which indicate that the effect of a per unit change of population on roundwood consumption (and indirectly on deforestation through roundwood consumption) is highest in Africa. The coefficients measure the slope or the relative change but not the absolute change, hence it is not necessary that the overall effect of population on roundwood consumption is highest in Africa. The elasticities indicate that a one percent change in population will increase roundwood consumption by 0.43, 0.43, and 0.55 percent in Latin America, Asia, and Africa, respectively. The other important explanatory factor of roundwood consumption is the *FCGA* (the absolute forest area). Its elasticity (0.39) indicates that even when population and *GDP* remain the same, the *FCGA* will increase the roundwood consumption by 0.39 percent for an increase of one percent in the *FCGA*. The dynamic interpretation of this is that as the forest area reduces over a period of time or forest policies are directed towards reducing the *FCGA*, roundwood consumption will automatically reduce due to the realisation of the scarcity of the resource. The elasticity of roundwood consumption with respect to *GDP* is 0.12 which is quite small as compared to population and the *FCGA*. The ranking of the three explanatory variables in the decreasing order is population, forest area, and *GDP* by the standardised coefficients as well as by the elasticities. The coefficients of the dummy variables of Africa and Asia are also significant and positive; and the values of coefficients of dummy variables result into the constant term being highest for Asia and lowest for Latin America. The R^2 of 0.92 is also quite high.

Forest Products Exports

Forest products exports are mainly concentrated in Asia. In the sample year, the contributions of Asia, Latin America, and Africa to the total exports of forest products were 83.34, 11.78, and 4.88 percent, respectively. The results of the forest products exports equation are given in Table 3. The results give some indications about the leading role of Asia in forest products exports. The exports in Asia are explained by the four explanatory variables which are ranked (in decreasing order), according to the stand-

TABLE 3. ESTIMATED COEFFICIENTS OF FOREST PRODUCTS EXPORTS EQUATION.

VARIABLE	COEFFICIENT	T-VALUE	STANDARDISED COEFFICIENT	ELASTICITY AT MEAN
PRFORAR1	0.057	2.16	0.00	0.01
PRFORAR2	7.946	6.02	0.31	0.10
PRFORAR3	0.624	10.23	0.03	0.53
GDPG2	10.524	1.58	0.04	0.08
DEBT1	0.001	6.25	0.05	0.06
DEBT2	0.024	6.47	0.58	0.76
TOT1	–0.023	5.39	– 0.03	–0.02
TOT2	–30.516	5.37	– 2.49	–5.12
DUMASIA	2551.000	4.90		
CONSTANT	0.724	2.45		

R^2 between observed and predicted values = 0.72.

ardised coefficient as well as the elasticity, as the terms of trade, the total debt, the percentage of the forest area, and the growth rate of *GDP*. The exports in Asia are elastic with respect to the terms of trade but inelastic with respect to debt, the percentage of forest area, and the growth rate of *GDP*. The exports in Latin America are explained by the three variables which are ranked in decreasing order by the standardised coefficients as well as the elasticities, as the total debt, the terms of trade, and the percentage of forest area. The marginal amounts of exports in Africa are explained by the percentage of the forest area only. The exports in Latin America and Africa are inelastic with respect to all its explanatory variables. The dummy variable of Asia is significant, and this makes the constant term of Asia to be different and higher than other two regions. The R^2 of 0.72 is also quite good.

Change in Cropland

The results of the change in the cropland equation are given in Table 4. The *CFGA* (absolute forest area), the growth in *GDP*, population, and the agriculture production index are the explanatory variables in all the three regions, but except the index of agriculture production, the value of the coefficients of other three variables are not the same in all the three regions. The value of the coefficient of forest area is highest in Asia, but the elasticity is highest in Latin America and lowest in Asia. The value

TABLE 4. ESTIMATED COEFFICIENTS OF THE CHANGE IN CROPLAND EQUATION.

VARIABLE	COEFFICIENT	T- VALUE	STANDARDISED COEFFICIENT	ELASTICITY AT MEAN
ABFORAR1	0.0011	7.57	0.50	0.60
ABFORAR2	0.0017	3.48	0.19	0.32
ABFORAR3	0.0012	12.22	0.20	0.49
GDPG	1.551	4.82	0.03	0.15
GDPG2	68.140	6.39	0.92	2.44
POP	0.572	4.71	0.42	0.83
POP2	–0.529	3.22	–0.39	–0.49
AGRPRI	1.118	10.41	0.11	5.40
DUMASIA	–300.180	6.00		
CONSTANT	–151.420	11.60		

R^2 between observed and predicted values = 0.62.

of the coefficient (1.55+68.14=69.69) as well as the elasticity of the growth of *GDP* is highest in Asia, and the coefficient in Asia is quite high as compared to the other two regions. The value of the coefficient (0.572–0.529=0.043) as well as the elasticity of the population variable is very low for Asia as compared to the same coefficient (0.572) and elasticity (0.83) for Latin America and Africa. The index of agriculture production has the same coefficient for all the three regions, and the elasticity is highest among all the variables for all the three regions. According to the values of elasticity, the explanatory variables for three regions are ranked (in decreasing order) as: the agriculture production index, population, the absolute forest area, and the growth in *GDP* for Latin America and Africa, and the agriculture production index, the growth in *GDP*, population and the absolute forest area for Asia. The change in the cropland is elastic only with respect to the agriculture production index in all the regions and with respect to the growth in *GDP* also in Asia. The dummy variable for Asia is significant and negative. This makes the constant term for Asia to be lowest among the three regions. The R^2 of 0.62 is also quite good.

Change in Pasture Land

The process of deforestation due to an increase in pasture land is mainly concentrated in the Latin American coun-

Table 5. Estimated Coefficients of the Pasture Land Equation.

Variable	Coefficient	t-value	Standardised coefficient	Elasticity at mean
PRFORAR1	0.706	3.25	0.06	0.22
GDPG1	42.076	7.26	0.27	0.26
DEBT1	0.010	4.30	1.34	1.59
TOT1	−0.234	4.54	−0.97	−0.63
CONSTANT	−1.372	0.79		

R^2 between observed and predicted values = 0.67.

tries. Hence, the change in pasture is regressed over the explanatory variables identified in the model section only for the Latin American countries. The results are given in Table 5. The change in pasture is elastic with respect to the total debt and inelastic with respect to the other three variables. The elasticity with respect to the term of trade is quite high as compared to the percentage of forest area and growth rate of *GDP*. The R^2 of 0.67 is also quite good.

Deforestation

The results of the deforestation equation are given in Table 6. The effect of roundwood consumption is the same across the regions. The effect of forest products exports is different in Asia as compared to Latin America, and there is no effect in Africa. The change in cropland effects are different in Africa than in Asia and Latin America. The impact of a change in pasture land occurs only in Latin America. The impacts of all the four variables are inelastic. The R^2 of 0.90 is quite high.

Table 6. Estimated Coefficients of the Deforestation Equation.

Variable	Coefficient	T- value	Standardised Coefficient	Elasticity at Mean
RWCONS	0.0009	7.02	0.09	0.09
FOPREXP1	11.383	6.39	0.43	0.25
FOPREXP2	0.349	23.36	0.27	0.13
CHCROPL	0.476	21.35	0.11	0.05
CHCROPL3	2.315	19.99	0.16	0.07
CHPAST1	1.344	10.41	0.46	0.26
CONSTANT	50.339	20.23		

R^2 between observed and predicted values = 0.90.

TABLE 7. THE COMBINED RESULTS OF ALL THE FIVE EQUATIONS.

VARIABLE	REGION		
	LATIN AMERICA	ASIA	AFRICA
Constant	50.339	50.339	50.339
RWCONS	0.0009	0.0009	0.0009
CONSTANT	–5740.0	6964.0	–2202.6
ABFORAR	0.313	0.313	0.313
TOTGDP	127.340	127.34	127.34
POP	264.000	264.00	614.84
FOPREXP	11.383	0.349	0.000
CONSTANT	0.724	2551.724	0.724
PRFORAR	0.057	7.946	0.624
GDPG		10.524	
TOT	–0.023	–30.516	
DEBT	0.001	0.024	
CHCROPL	0.476	0.476	2.791
CONSTANT	–151.42	–451.60	–151.42
ABFORAR	0.0011	0.0017	0.0012
GDPG	1.551	69.691	1.551
POP	0.572	0.043	0.572
AGRPRI	1.118	1.118	1.118
CHPAST	1.344	0.000	0.000
CONSTANT	–1.372		
PRFORAR	0.706		
GDPG	42.076		
DEBT	0.010		
TOT	–0.234		

The combined results of the four equations of the first-level causes and the equation of deforestation are necessary for understanding the total mechanism of deforestation. Hence, the combined results for three different regions are separately given in Table 7.

Impact of Different Causes on Deforestation

To have some comparative insights of the deforestation process across the three regions, the impacts of some first-level (direct) and second-level (indirect) causes are discussed next.

Direct Causes

Out of the four direct causes, only three causes, the exports of forest products, the change in cropland and pasture are discussed in the literature extensively. Hence, these three causes are discussed here separately, and the fourth cause (roundwood consumption) is discussed along with population (a secondary cause).

Exports of Forest Products

The results of exports are stimulating. The coefficient of exports indicate that the exports of forest products of worth 1 million US dollars result 11,383 and 349 hectares deforestation in Latin America and Asia, respectively. In Asia, the lower coefficient does not mean deforestation is lowest due to exports. It means that a small portion of the exports material is coming from deforestation and a large portion from the regular forest harvesting activities, which seems true for Asia due to forest products exports promotion policies of many Asian countries such as Indonesia, Malaysia, and the Philippines (Repetto, 1988, pp. 20–21). Out of the 35 African countries of the sample, exports from 26 countries were almost zero. Hence, the lack of an effect of exports in Africa is also consistent with reality.

Cropland

The results of cropland are very interesting. In Africa, a one hectare increase in cropland causes 2.79 hectares of deforestation, while in Asia and Africa it causes 0.476 hectares of deforestation. The value of 2.79, which is greater than 1, of the cropland coefficient may seem problematic. But it is quite consistent to our argument, in the section of theoretical model, for the demand of forest land. Two reasons may be suggested for the value of coefficient greater than 1. First, the variable may be picking up the deforestation due to other developmental projects such as road construction etc. Second, there may be a lot of wasteful conversion in the process of diverting the forest land to cropland. The results indicate that in Asia and Latin America only about 48 percent of the increase in cropland is coming from the forest and the remaining 52 percent from other sources like village wastelands, wood lands, and other lands.

Pasture

The results of pasture indicate that increase of one hectare in pasture causes 1.344 hectares of deforestation in the Latin American countries. This value of coefficient (greater than one) is parallel to the value of cropland coefficient in Africa, and the same two reasons must be responsible here also. However, there are three limitations of these coefficients of cropland and pasture. First, we cannot be sure of the reason. Second, even if we assume that these two are the only reasons, we cannot calculate the contribution of each cause. Third, in the case of Asia, the coefficient of cropland is less than one and the coefficient of pasture is zero, and hence the contribution of other demands is not being picked up. These limitations should be kept in view in interpreting the overall results of the model.

Second-level (Indirect) Causes

The most discussed second-level causes are population, debt, and *GDP*. Here, these causes are discussed in detail, while other causes are briefly discussed.

Population

Population works through roundwood consumption and cropland. The coefficient of roundwood consumption (0.0009) over all the three regions indicates that 1000 cubic mt. of roundwood consumption leads to 0.9 hectares of deforestation. The world's average growing stock is 112 cubic mt. per hectare (Sharma, 1992, pp. 550–553), which means that for 1000 cubic mt., 8.9 hectares of forests have to be cleared, or, that approximately 10.1 percent of the consumption requirement is being met through deforestation. However, population has a different impact on deforestation in the three regions. A population of one million leads to 264, 264, and 614.84 thousand cubic mt. roundwood consumption, which results in 238, 238, and 553 hectares annual deforestation in Latin America, Asia, and Africa, respectively. Population also causes deforestation through an increase in cropland. A population size of one million also results 572, 43, and 572 hectares deforestation through cropland in Latin America, Asia, and Africa, respectively. Hence, the total effect of a population of one million is 810, 281, and 1125 hectares deforestation in Latin America, Asia, and Africa, respectively.

This result is in conformity with general observations about increasing population being a serious threat to forests in Africa.

Debt

In Asia, the debt variable affects deforestation through exports of forest products , and in Latin America through exports of forest products and change in pasture. Debt of one million US dollars is leading to 1.24 and 24.19 thousand US dollars exports of forest products, and that in turn to 14.1 and 8.4 hectares of annual deforestation in Latin America and Asia, respectively. In Latin America, debt of one million US dollars is also leading to 9.8 hectares increase in pasture which leads to 13.1 hectares of deforestation. Hence, the total effect of one million US dollar debt is 27.2 hectares deforestation in Latin America, which is almost three times of the effect in Asia.

Gross Domestic Product

The total *GDP* influences deforestation through roundwood consumption, and the growth of *GDP* works through exports, cropland, and pasture. One billion US dollar *GDP* causes 114.6 hectares deforestation through increased roundwood consumption in all the regions.

On the other hand, one percent growth rate causes 738; 33,185; and 4,329 hectares deforestation through cropland in Latin America, Asia, and Africa, respectively. A one percent growth rate also causes 3,669 hectares deforestation through exports in Asia, and 56,537 hectares through pasture in Latin America. Hence, the total effect of one percent growth rate is 57,275; 36,854; and 4,329 hectares deforestation in Latin America, Asia, and Africa, respectively.

Terms of Trade

The favourable terms of trade (less export prices) also encourage deforestation in Asia and Latin America. The *TOT* being an index of the ratio of export and import prices, the favourable *TOT* means the index is smaller. A decrease of one point in *TOT* increases forest products export by 30.52 and 0.02 million US dollars that in turn causes 10,640 and 263 hectares of deforestation in Asia and Latin America, respectively. In Latin America, a decrease of one point in *TOT* also causes 315 hectares deforestation through pasture.

Agriculture Production Index

It works through cropland. A one point increase in the index causes 532, 532, and 3120 hectares of deforestation in Latin America, Asia, and Africa, respectively.

FCGA or Absolute Forest Area

The remaining variable is the extent of forest area. One thousand hectares of the forest area leads to 0.28 hectares of deforestation through roundwood consumption in all the three regions, and 0.53, 0.58, and 3.43 hectares deforestation through cropland conversion; the two effects combined together lead to 0.81, 0.86, and 3.71 hectares deforestation in Latin America, Asia, and Africa, respectively. In addition to this, a one percent increase in forest area will also lead to 644 and 949 hectares of deforestation in Latin America through exports and pasture, respectively, and 2,770 hectares deforestation through exports in Asia. But higher deforestation in high forest area countries should not be interpreted as inevitable. As we discussed in the model section, the coefficients of the forest area represent the *FCGA*. Hence, by appropriate policy interventions the effect of forest area variable on deforestation can be reduced. Similarly, the coefficient of the percentage of forest area represents the effect of comparative advantage of the export (forest or meat) products, and by export policy interventions, the effect of the percentage of forest area can also be reduced.

Elasticities of Deforestation

In addition to the insights given by the above discussion of the coefficients of different causes of deforestation, the relative responsiveness of deforestation with respect to different causes (elasticities) will provide important information for decision makers. The elasticities given in Tables 3, 4, 5, and 6 are for the global mean values of the independent and dependent variables, and do not provide the variation across the regions. Hence, the elasticities are calculated for each country. The elasticities of deforestation with respect to selected first and second-level causes for a country of highest annual deforestation in each region, and mean and maximum values for each region are given in Table 8. The comparison of mean values across the regions and of different causes within the re-

TABLE 8. ELASTICITIES OF DEFORESTATION.

REGION	VARIABLES						
	RWCONS	*FOPREXP*	*CHCROPL*	*POP*	*ABFORAR*	*PRFORAR*	*DEBT*
Africa							
Zaire	0.04		1.06	0.10	0.90		
Mean	0.80		7.34	1.87	0.52		
Max.	13.26[1]		194.01[1]	37.18[1]	2.14[1]		
Asia							
Indon.	0.13	0.83	0.08	0.04	0.10	0.15	0.40
Mean	0.23	0.37	0.26	0.17	0.09	0.81	0.73
Max.	0.71[2]	2.26[3]	0.61[4]	0.77[5]	0.36[6]	2.85[7]	2.40[5]
L. Am.							
Brazil	0.06	0.55	0.09	0.02	0.12	0.03	0.83
Mean	0.31	1.91	0.07	0.20	0.05	0.48	2.10
Max.	3.41[8]	11.02[9]	0.25[8]	2.19[8]	0.21[10]	1.47[9]	8.41[9]

Indon.=Indonesia, *L. AM.*= Latin America.

[1] Rwanda, [2] India, [3] Malaysia, [4] Pakistan, [5] Bangladesh, [6] Papua N.G, [7] Sri Lanka, [8] Haiti, [9] El-Salvador, [10] Peru.

gions and countries (of highest deforestation in each region) will provide some policy recommendations for controlling deforestation.

The higher mean values of the two first-level causes (*RWCONS* and *CHCROPL*) in Africa (as compared to Asia and Latin America) indicate that the response of policies designed to reduce deforestation through either of these two causes will be higher in Africa. An intra-regional comparison of the four direct causes indicates that the response will be highest for *CHCROPL* in Africa, and *FOPREXP* in Asia and Latin America. The analysis of second-level causes indicates that the response will be maximal for population measures in Africa, debt measures in Latin America, and the policies which will reduce the comparative advantage of forest products in exports in Asia.

The comparison of mean values gives an aggregate picture at the regional level. However, the national picture of many countries may be entirely different from the aggregate one. For example, in Zaire the elasticities with respect to the first-level causes *RWCONS* and *CHCROPL* are very small as compared to the mean values of Africa, but the elasticity with respect to *ABFORAR* (one of the second-level causes) is quite high as compared to the mean value for Africa. Hence, for Zaire, the highest value of *ABFORAR* among second- level causes indicates that deforestation controlling policy planners should modify the policies which encourage the *FCGA*. Low values for *POP* also indicate that population control policies will not respond much in Zaire. In Indonesia and Brazil, the first attack of deforestation controlling policies should be on debt, and the second on policies which put forest products on the comparative advantage for exports and policies which encourage *FCGA*, respectively.

The highest values for each region also provides some interesting results. The cases of a few countries are discussed in short. In Asia, the elasticity with respect to *RWCONS* is highest for India (0.71). In India, the deforestation elasticities with respect to *FOPREXP* (0.02) and *CHCROPL* (0.28) are quite low as compared to *RWCONS*. The elasticities of *RWCONS* with respect to *ABFORAR*, *GDP*, and *POP* are 0.07, 0.11, and 0.83, respectively, and the elasticities of deforestation with respect to these variables are 0.18, 0.08, and 0.64, respectively. These values indicate that in India, deforestation is most responsive for roundwood consumption which has the highest elasticity with respect to population. Similar is the case of Bangladesh, where the elasticity of deforestation with respect to population (0.77) is highest among all the Asian countries. Hence, in these two countries, policies to control deforestation should be directed towards population. The elasticity with respect to *FOPREXP* is highest (2.26) in Malaysia, and the elasticity of *FOPREXP* is highest with respect to *TOT* (0.88) as compared to three other variables *PRFORAR* (0.20) *GDPG* (0.02) and *DEBT* (0.18). Hence, the policies directed towards increasing the export prices of forest products will be more effective in Malaysia.

In Africa, the elasticities with respect to *RWCONS* (13.26) and *CHCROPL* (194.01) are highest in Rwanda, and the elasticities with respect to population (37.18) and absolute forest area (2.14) are also highest in Rwanda. Hence, in Rwanda, deforestation control policies have to be directed towards appropriate changes in the population and the *FCGA* encouraging policies.

In Latin America, the elasticity with respect to

RWCONS (3.41) and *CHCROPL* (0.25) is highest in Haiti, and these are mainly driven by population. The elasticity with respect to population (2.19) is also highest in Haiti. The elasticity with respect to *FOPREXP* (11.02) is highest in El-Salvador and is driven by debt and *TOT*. Hence, forest policies have to be directed towards population control in Haiti, and towards reduction in debt and increase in export prices of forest products in El-Salvador.

The elasticities can also be used to gain a comparative view of the few selected countries. In Southeast Asia, the export of forest products has been identified as the major source of deforestation. Hence, a comparative analysis of the elasticities of three countries- Indonesia, Malaysia, and Philippines is discussed next. The elasticities of deforestation with respect to three first- level causes, and the elasticities of forest products exports with respect to the four second-level causes are given in Table 9.

In all the three countries, the elasticity of deforestation with respect to the exports of forest products is highest among the three first-level causes. Hence, in these three countries, deforestation will be most responsive to policies directed towards the reduction of forest products exports. The elasticities of forest products exports are also highest with respect to the same second-level explanatory variable i.e., *TOT*, in all the three countries. But the elasticities of forest products exports with respect to *TOT* are quite different in the three countries. Hence, the responsiveness of forest product exports to a uniform percentage change in export prices will be highest in Philippines and lowest in Indonesia. In Indonesia and Philippines, the elasticity of exports with respect to debt are also

Table 9. Elasticities of Deforestation for Three Southeast Asian Countries.

Country	Def. Elas.			Fpe. Elas.			
	RWCONS	*FOPREXP*	*CHCROPL*	*PRFORAR*	*GDPG*	*DEBT*	*TOT*
Indonesia	0.13	0.83	0.08	0.18	0.02	0.45	0.74
Malaysia	0.05	2.26	0.13	0.20	0.02	0.18	0.88
Philippines	0.11	0.31	0.00	0.90	0.03	2.51	12.03

Def. Elas.: Deforestation elasticity with respect to,

Fpe. Elas.: Forest product export elasticity with respect to.

quite high as compared to the elasticities with respect to *PRFORAR* and *GDPG*, and hence, in these countries, the next attention should be on the policies directed towards reduction in debt. In Malaysia, the elasticity with respect to *PRFORAR* is second highest, but it is not much different than the elasticity with respect to debt. Hence, in Malaysia, after *TOT* the policies should be directed towards changing the policies which put forest products into comparative advantage and the policies to reduce the debt.

CONCLUSIONS

So far, most of the cross-sectional studies have merely tried to establish the causal relationship between different causes and deforestation, and sometimes very contradictory results have been reported. This study extends the cross-sectional studies beyond just establishing the causal relationship, and demonstrates that a detailed econometric model can also be used for broad-level policy issues even at a global level. The study demonstrates that a cross-sectional econometric model can be designed and estimated to capture the variation of explanatory variables as well as different effects of a variable across the regions. The results of the study confirms that the causes of deforestation vary across the regions, and validates many theoretical and descriptive explanations of deforestation. The results also prove that a global prescription for deforestation may not be an appropriate solution.

The results of the model are definitely subject to the limitations of the data. Most of the authors have argued about the validity of deforestation data, but we feel that validity of all the data related to land i.e. cropland and pasture are as much subject to non-reliability as deforestation data. Hence, the results of the model cannot be used in absolute terms. However, the methodology presented definitely demonstrates the increased scope of the cross-sectional global studies. The discussion of the effect of different first and second-level causes on deforestation can be used for comparative analysis across the regions. The elasticity analysis also demonstrates that such a study can provide very important information for national agencies and international development agencies for policy interventions or suggestions at the national level.

ACKNOWLEDGEMENTS

The authors are indebted to Dr. R. A. Berry, Department of Economics, University of Toronto, Toronto; Dr. J. C. Nautiyal, Faculty of Forestry, University of Toronto, Toronto; Dr. B. Knerr, Agricultural Economics Department for Tropical and Subtropical Agriculture, University of Hohenheim, Stuttgart-Hohenheim; and three anonymous reviewers and the editor of the journal. However, any errors are the responsibility of the authors.

REFERENCES

Allen, J. C. & Barnes., D. F., 1985. The Causes of Deforestation in Developing Countries. Annals of the Association of American Geographers, 75(2), 163–184.

Bajracharya, D., 1983. Fuel, Food, or Forest? Dilemmas in a Nepali Village. World Development, 11(12), 1057–1074.

Barbier, E. B., Burgess, J. C., & Markandya, A., 1991. The Economics of Tropical Deforestation. Ambio, 22(2), 55–58.

Binswanger, Hans P., 1991. Brazilian Policies That Encourage Deforestation in the Amazon. World Development, 19(7), 821–829.

Bowonder, B., 1982. Deforestation in India. International Journal of Environmental Studies, 18, 223–236.

Bundestag, D., 1990. Protecting the Tropical Forests. 2nd Rep. of Enquete Commission. (Bonner Universitats, Bonn).

Capistrano, Ana D., 1994. Tropical Forest Depletion and the Changing Macro Economy, 1967-85. In The Causes of Tropical Deforestation, edited by Katrina Brown and David W. Pearce (London: UCL Press), pp. 68–85.

Capistrano, Ana D. & Kiker, C. F., 1990. Global Economic Influences on Tropical Closed Broad-leaved Forest Depletion, 1967-1985. Paper presented at International Society for Ecological Economics Conference, Washington DC USA.

Chakraborty, M., 1994. An Analysis of the Causes of Deforestation in India. In The Causes of Tropical Deforestation, edited by Katrina Brown and David W. Pearce (London: UCL Press), pp. 226–238.

Constantino, L. F. & Ingram, D., 1990. Supply-demand Projections for the Indonesian Forestry Sector. Director General of Forest Utilization, Ministry of Forestry, Government of Indonesia, Jakarta.

Fearnside, P. W., 1982. Deforestation in the Brazilian Amazon: How Fast it is Occurring? Interciencia, 7(2), 82–88.

Feldstein, M. S., 1982. Inflation, Tax rules and Investment: Some Econometric Evidence. Econometrica, 50, 825–862.

Food and Agriculture Organization (FAO), 1993. Forest Resources Assessment 1990: Tropical Countries (Rome: FAO).

Grainger, A., 1993. Controlling Tropical Deforestation (London: Earthscan Publications Ltd.).

Gillis, M., Perkins, D. H., Roemer, M., & Snodgrass, D. R., 1992. Economics of Development (New York: W. W. Norton).

Jantz, U., 1993. World Resource Assessment: An Overview. Unisylva, 44(74), 3–9.

Jepma, C. J., 1995. Tropical Deforestation: A Socio-economic Approach (London: Earthscan Publications Ltd).

Kahn, J., & McDonald, J., 1994. International Debt and Deforestation. In The Causes of Tropical Deforestation, edited by Katrina Brown and David W. Pearce (London: UCL Press), pp. 57–67.

Kahn, J., & McDonald, J., 1992. Third World Debt and Tropical Deforestation. Unpublished paper, Department of Economics, SUNY-Binghampton, New York.

Kennedy, P., 1992. A Guide to Econometrics. (Cambridge: The MIT Press).

Kummer, D. M., 1992. Deforestation in Post-war Philippines (Chicago: Chicago University Press).

Kummer, D. M., & Chi Ho Sham., 1994. The Causes of Tropical Deforestation: A Quantitative Analysis and Case Study from the Philippines. In The Causes of Tropical Deforestation edited by Katrina Brown and David W. Pearce (London: UCL Press), pp. 146–158.

Larson, Bruce A., & Bromley, D. W., 1991. Natural Resource Prices, Export Policies, and Deforestation: the Case of Sudan. World Development, 19(10), 1289–1297.

Leamer, Edward E., 1987. Sources of International Comparative Advantage (Cambridge: MIT Press).

Lombardini, C., 1994. Deforestation in Thailand. In The Causes of Tropical Deforestation edited by Katrina Brown and David W. Pearce (London: UCL Press).

Lugo, A. E., Schmidt, R., & Brown, S., 1981. Tropical Forests in the Caribbean. Ambio, 10(6), 318–324.

Lugo, A. E., and Brown, S., 1982. Conversion of Tropical Moist Forests: A Critique. Interciencia, 7, 89–93.

Myers, N., 1994. Tropical Deforestation: Rates and Patterns. In The Causes of Tropical Deforestation edited by Katrina Brown and David W. Pearce (London: UCL Press), pp. 27–40.

Osgood, D., 1994. Government Failure and Deforestation in Indonesia. In The Causes of Tropical Deforestation edited by Katrina Brown and David W. Pearce (UCL Press). pp. 217–225.

Panayotou, T., & Sungsuwan, S., 1994. An Econometric Analysis of the Causes of Tropical Deforestation: the Case of Northeast Thailand. In The Causes of Tropical Deforestation edited by Katrina Brown and David W. Pearce (London: UCL Press), pp. 192–210.

Palo, M. 1987. Deforestation Perspectives for the Tropics: a Provisional Theory With Pilot Applications. In The Global Forest Sector: An Analytical Perspective edited by D. Dykstra, M. Kallio, and C. Binkley (Chichester, England: International Institute for Applied Systems Analyses and John Wiley), pp.57–89.

Palo, M. 1994. Population and Deforestation. In The Causes of Tropical Deforestation edited by Katrina Brown and David W. Pearce (London: UCL Press), pp. 42–56.

Pearce, D., & Brown, K., 1994. Saving the World's Tropical Forests. In The Causes of Tropical Deforestation edited by Katrina Brown and David W. Pearce (London: UCL Press), pp. 2–26.

Pindyck, R. S., & Rubinfeld, D. L., 1991. Econometric Models and Economic Forecasting (New York: McGraw Hill, Inc).

Reis, E., & Guzman, R., 1994. An Econometric Model of Amazon Deforestation. In The Causes of Tropical Deforestation edited by Katrina Brown and David W. Pearce (London: UCL Press), pp. 172–191.

Repetto, R. 1988. The Forest for the Tress: Government Policies and the Misuse of Forest Resources (Washington DC: World Resource Institute).

Richard, J. F., & Tucker, R. P., 1988. World Deforestation in Twentieth Century (Durham: Duke University Press).

Rowe, R., Sharma, N. P., & Browder, J., 1992. Deforestation: Problems, Causes, and Concern. In Managing the World's Forests: Looking for Balance Between Conservation and Development edited by N. P. Sharma (Iowa: Kendall/Hunt Publishing Company), pp. 33–46.

Rudel, T. K., 1989. Population, Development, and Tropical Deforestation: A Cross-national Study. Rural Sociology, 54(5), 327–338.

Rudel, T. K., 1994. Population, Development and Tropical Deforestation: A Cross-national Study. In The Causes of Tropical Deforestation, Edited by Katrina Brown and David W. Pearce (London: UCL Press), pp. 96–105.

Sandler, T., 1993. Tropical Deforestation: Markets and Market Failure. Land Economics, 69(3), 225–233.

Saxena, A., and Nautiyal, J. C. 1996. Analyzing Deforestation: A Systems Dynamic Approach. Faculty of Forestry, University of Toronto, Toronto. Unpublished.

Shafik, N., 1994. Macroeconomic Causes of Deforestation: Barking Up the Wrong Tree? In The Causes of Tropical Deforestation edited by Katrina Brown and David W. Pearce (London: UCL Press), pp. 86–95.

Sharma, N. P., 1992. Managing the World's Forests: Looking for Balance Between Conservation and Development (Iowa: Kendall/Hunt Publishing Company).

Southgate D., Sierra, R., & Brown, L., 1991. The Causes of Tropical Deforestation in Ecuador: a Statistical Analysis. World Development, 19(9), 1145–1151.

Theil, H., 1971. Principles of Econometrics (New York: John Wiley).

Torsten, A., 1992. Deforestation of Tropical Rain Forest: Economic Causes and Impact on Development (Tubingen: J. C. B. Mohr)

United Nation Development Program (UNDP) 1992. Human Development Report 1992 (New York: Oxford University Press).

Walker, R. T., 1987. Land Use Transition and Deforestation in Developing Countries. Geographical Analysis, 19, 18–30.

Winterbottom, R., 1990. Taking Stock: The Tropical Forestry Action Plan After Five Years (Washington DC: World Resource Institute).

World Bank. 1991., The Forestry Sector: a World Bank Policy Paper (Washington DC: World Bank).

World Resource Institute., 1985. Tropical Forests: A Call to Action (Washington DC: World Resource Institute and the World Bank).

World Resource Institute., 1992. World Resources 1992–93 (New York: Oxford University Press).