The University of Sydney

School of Economics and Political Science

Working Papers

A Re-examination of Causes of Deforestation and Environmental Kuznets Curve: Evidences from Latin America, Africa and Asia

Richard Culas and Dilip Dutta

ECON2003-2
Discipline of Economics

Faculty of Economics and Business

e+b

ISBN : 1 86487 541 0 **ISSN 1446-3806**
February 2003

A Re-examination of Causes of Deforestation and Environmental Kuznets Curve: Evidences from Latin America, Africa and Asia

Richard Culas and Dilip Dutta
School of Economics and Political Science
University of Sydney, Australia

Email: seps@econ.usyd.edu.au

ABSTRACT

Previous cross-country regression analyses on the causes of deforestation seem to have misspecified the regression models, in which the causes at different levels are mixed, leading to flawed cause-effect relationship between the rate of deforestation and its explanatory variables. The paper focuses explicitly on underlying/policy-oriented causes of deforestation and then examines their relationship with rate of deforestation across 43 countries of Latin America, Africa and Asia. An environmental Kuznets Curve (EKC) relationship between rate of deforestation and income is also tested. Results across all regions and based on panel data technique show that forest and allied (non-forest) sector policies and population density increase deforestation, while forest products export promotion policies, export prices and technological progress decrease deforestation. The effects of per capita income, economic growth and agricultural production are found to be varying in different region. An inverted U-shaped EKC empirically fits for Latin America and Africa while a U-shaped EKC does the same for Asia.

JEL CLASSIFICATION:
KEYWORDS: deforestation; underling/policy-oriented causes of deforestation; environmental Kuznets Curve; cross-country analysis; Latin America; Africa; Asia

CONTENTS PAGE

1. Introduction

The large-scale depletion of tropical forest is one of the most serious environmental problems in recent times. It has become an issue of global concern because of tropical forest's relevance in biodiversity conservation and in limiting the greenhouse effect. Forest depletion[1] also affects economic activity and threatens livelihood and cultural integrity of forest-dependent people at local level. It reduces supply of timber and other forest products, and causes siltation, flooding and soil degradation. Tropical rain forest, in particular, constitutes about 41 percent of total tropical forest cover on the earth's land surface. It is the richest and the most valuable ecosystem that provides habitation for between 50 and 90 percent of all species on earth [47]. For example, during the 1980s about 15.4 million hectares of tropical forests were lost annually [15]. The annual loss was at 12.7 million hectares between 1990 and 1995 [16]. At global level, tropical deforestation accounts for about 25 percent of the heat trapping emissions [20].[2]

Most of the forest depletion happens in tropical developing countries where the status of development and welfare of the citizens are crucial factors in determining the extent of the forest depletion. Poverty, over-population and indebtedness accentuate deforestation in many of the low-income tropical countries. The requirement for economic growth and expansion of income result in growing demand for agricultural and forest derived products. Such trend is quite unlikely in many developed countries where higher level of

[1] The term 'forest depletion' includes deforestation and forest degradation or a combination of both. Several studies may use different definitions for deforestation and forest degradation. The Food and Agricultural Organization (FAO) of the United Nations defines deforestation mainly as loss of the forest cover attributed to over less than 10 per cent of the crown cover, whereas forest degradation as a loss of the forest's production capacity. Our interest here is, however, on the causes of these processes than with the conceptual precision of the terms deforestation and forest degradation.

[2] Reliability of the FAO *Tropical Resources Assessment* [15] estimates on the loss of forest area is questionable because of the poor definition and the data used [37]. Further, it is also dubious whether the annual reduction in the loss of forest area between the periods 1990-1995 is a representation of slowdown in the actual forest clearance, or new definition and better data used by the FAO [3].

(national) income growth leads to changes in the composition of demand for goods and services, with greater demand for environmental services. In recent literature, this trend is characterized as an inverted-U shaped Kuznets curve relationship between income growth and environmental quality (i.e. an environmental Kuznets Curve).

In many cases, however, the studies of deforestation do not provide a clear picture of its causes. The causes seem to vary from place to place in almost idiosyncratic fashion. For example, international timber trade has played a major role in Southeast Asia but only a minor role in Latin America, whereas cattle ranches (pasture) has caused much deforestation in Latin America and little deforestation in anywhere else [26, 37, 44]. Further, among the causes of deforestation, agricultural expansion is believed to be responsible for about 50-60 percent of overall deforestation. Other deforestation activities like cattle ranching (pasture) and fuel wood collection together are in the range of 15-20 percent. About 20 percent of deforestation is due to logging, but its indirect effect may be higher when migrating cultivators occupy these logged areas. The rest of deforestation activities (due to roads and infrastructure development, hydropower development, plantations, resettlements programs, etc.) are at lesser levels [24, 45].

Many of human-induced deforestation and forest degradation are in varying degrees considered as economically wasteful, environmentally negative and socially undesirable. Even though some types of deforestation and forest degradation result in benefits to the society, the associated costs amply exceed the benefits (no matter how these are measured) and, therefore, those types of deforestation and forest degradation are simply inappropriate [11]. If this is so, question arises: why do inappropriate deforestation and forest degradation occur and what are the underlying causes of such forest depletion?

In view of answering the above questions, there have been an increased number of economic models attempting to link deforestation to different socio-economic, demographic and political variables. A critical review of formal economic models of tropical deforestation can be found in Angelsen and Kaimowitz [3]. A single category of economic model that seems to dominate the deforestation literature is the macro level regression models. Brown and Pearce [8] also provide a comprehensive survey of recent studies on this type of models. Some other studies to mention are Tole [44], Koop and Tole [27] and Bhattarai and Hammig [6]. One needs, however, to take a critical look at these macro econometric studies for one or other econometric and/or methodological reasons.

Generally, four of the econometric and methodological issues are discussed as the shortcomings of these macro level econometric studies[3]. In this paper, however, we discuss an econometric issue, *i.e.* misspecification of regression models, which can often be found in the literature on cross-country regression analysis of tropical deforestation. Following a brief discussion on the issue of misspecification of regression models in section 2, we present the variables selected for our analysis, their likely impacts, and the data sources in section 3. Section 4 focuses on our empirical model designed and estimation techniques applied. Results and their implications related to our model are discussed in section 5, followed by a conclusion in section 6.

2. Misspecification of Regression Models

Many of the previous studies lack an explicit theoretical framework or model that guides the empirical analysis in both selection and interpretation of explanatory variables. The variables (causes of deforestation) are distinguished at three different levels (see Figure 1). At level 1, agent induced (*direct*) causes of deforestation are considered. This includes expansion of agricultural land, cattle ranching, logging and fuel wood collection as taken up by individual *agents* involved in deforestation. At level 2, the *intermediate* (or structural-institutional-technological) causes of deforestation are considered. They are the *decision parameters* of the agents at level 1. Some possible examples are agricultural input and output prices, level of technology, land distribution, wage levels, property rights, etc. At level 3, the policy-oriented (*indirect*) causes of deforestation are considered. They are the

[3] Four of those issues are on specification of regression models, reliability of the deforestation estimates, problem of cross-country heterogeneity and problems involved in finding environmental Kuznets Curve (EKC) for deforestation.

macro-level variables and policy instruments that influence deforestation through the other two levels. These variables do not enter into the agent's decision problem directly, but they influence through the decision parameters at the level 2. Examples should include national income level, economic growth, foreign debt, export prices, demographic factors and macro level policy instruments [3, 4].

Many of the previous econometric models mix direct, intermediate and underlying/policy-oriented causes in their explanatory variables. For example, foreign debt, fuel wood collection and agricultural prices are introduced in the same model. Thus the result creates confusion over the cause-effect relationships. Because an explanatory variable may be a function of some other explanatory variable, interpretation of the causal effects is flawed. Statistically this may result in high levels of multicollinearity (ie. misspecification of regression models). One should, therefore, think it is imperative to distinguish the variables at different levels, and to limit the analysis to a particular level [3, 4, 26][4].

3. Data and Model Specification

Our sample consists of a total of 43 tropical developing countries from Africa, Asia and Latin America for the period of 1971-94. The list of countries for the three regions is presented in Table 3 in Appendix 1. The list excludes the Middle East oil economies and North African countries, and many others. But the listed countries provide a comparable set of environmental and economic conditions across a wide geographic area. Africa sample includes 23 countries, Asia 11 countries and Latin America 9 countries. Due to non-availability of data on some of the variables for the entire period 1971-94, the data for all three regions are unbalanced with 330 observations for Africa, 190 for Asia, and 199 for Latin America.

[4] An exception to this general picture is a study by Kant and Redantz [26] that links the level 3 variables to deforestation through level 1 variables and therefore uses a two-stage recursive equation system for model estimation. Another exception is a study of Angelsen *et al.* [4] that links the level 2 variables to deforestation through the level 1 variable (agricultural land expansion).

(a) Forest area definition (rate of deforestation)

Rate of deforestation is defined as the percentage annual decrease in forest area (minus the percentage change in forest area mean rate of afforestation). Forest area is forest cover that includes forests and all woody vegetation. FAO *Production Yearbook* provides the most comprehensive definition for forest cover - *to include closed and open forests, woodland, plantations, and land from which forests have been cleared (deforested) but which will be reforested in the near future.* The reasons for the use of forests and woodland to estimate the rate of deforestation is that incommensurable definitions of forest area by other sources have made comparison of deforestation estimates difficult [1], and made it hard to establish global generalization regarding the causes of deforestation.

By using a broad definition for forest, however, the problems associated with inconsistencies and the use of restrictive forest definitions can be largely avoided. The broad definition allows also for greater versatility of measurement with respect to changes in a wide variety of forest vegetative types. This data are more reliable and the only source covering many countries and spanning a longer period than other sources. Only a limited number of studies have used the data from the FAO *Production Yearbook* in the analyses of causes of deforestation [6, 12, 27].

(b) Explanatory variables

Since deforestation is the result of a complex process generated by different causes at different levels, we specify the following underlying/policy-oriented causes that seem to be theoretically important for our model. A quadratic term of the GDP per capita is specified for the EKC relationship and time trend is used as an indicator for the effects of other exogenous time dependent variables.

(i) Free Common Good Attitude (absolute forest area)

In tropical developing countries forest sector and allied (non-forest sector) policies often encourage general public to undervalue forest resources. Such policies within forest sector include timber concessions, low royalties and license fees, insecure land tenure and incentives for wood processing industries. The policies outside the forest sector include agricultural programs that clear land for estate crops, policies related to tax, credit and prices that stimulate private investment for competing land uses, and transmigration policies that encourage infrastructure development and resettlements of people [Repetto cited in Kant and Redantz, p. 58]. These government policies together with the physical nature of forest (i.e. actual forest area) reflect the *Free Common Good Attitude* (FCGA) of people towards forests. The FCGA influences consumption of forest derived products and clearing of forestland for alternative land uses. Thus, the stronger is the FCGA, the higher will be the consumption of forest derived products and the alternative land uses, hence, the rate of deforestation. Due to lack of any uniform quantifiable measure of government policies over the tropical countries, only absolute forest area is used as a measure for the FCGA [Kant and Redantz, pp. 58-59].

(ii) Comparative Advantage of Forest Products (proportion of forest area)

Exports of the developing economies historically have been based on primary products of forestry, agricultural and mineral sectors, which contribute significantly to their economic growth. In the present context, we focus our attention on the export of forest products and therefore question of C*omparative Advantage of Forest Products* (CAFP) over other products automatically arises. The CAPF with respect to other products depends on both the proportion of forest area to the total land area and the forest product export promotion policies of national governments. Due to limitations on the measurement of the government policies, only the proportion of forest area has been used to represent the CAFP [Kant and Redantz, p. 60].

(iii) Agricultural production index

Agricultural sector is a major contributor to the economies of many tropical developing countries. It contributes to GDP, employment and exports. Agricultural expansion into forest is thus considered as a major strategy to increase agricultural production and income. Expansion of agricultural land into forestland is, however, due to two different activities of agriculture. Some people migrate into tropical forest areas for subsistence needs and are called *shifting cultivators*. The other people converting forestland permanently for export crops are *commercial farmers* [4].[5]

Agricultural production index is therefore considered as an explanatory variable to explain the effects of these activities on deforestation. This index is an aggregate volume of agricultural production in which international commodity prices are used to facilitate comparative analysis of productivity at national level (*www.fao.org*).

(iv) Population density

Population pressure increases deforestation because of ever increasing demand for forest products and alternative land uses. The growing population will also supply abundant labour that will affect the labour markets by pushing down the wage rates and high unemployment rate that may further increase the pressure on forests. Population pressure may, on the other hand, contribute to reduce the rate of deforestation by innovation, inducing technological progress and institutional changes in agriculture and forestry sectors. That initially population growth may cause increased deforestation, but once the growth reaches a certain level, production processes are often changed to improve efficiency, which, in turn, conserve the remaining forest resources [43]. Considering this controversial role of population pressure on deforestation, it is evidenced that population pressure would increase rate of deforestation [for example, see 9, 25, 33]. Although the effect of population pressure is by rural population or overall population, it is hypothesized that an increase in population density will lead to increased deforestation.

(v) GDP per capita

It is hypothesized that GDP per capita stimulate demand for agricultural and forest derived products that causes deforestation. A high level of GDP per

[5] Shifting cultivators are peasant farmers who derive their livelihoods mainly from agriculture, utilise mainly family labour in farm productions, and are characterised by partial engagement in input and
output markets which are often imperfect or incomplete. But the commercial farmers are big farmers usually integrated into national or international markets [Ellis, p. 13].

capita, on the other hand, reduces the pressure on forests if it demands that forests be protected rather than depleted. The latter is the case in the past in many of developed countries where with economic development they valued more the environmental services that forests provide. A high level of GDP per capita may also reduce the pressure on forests by other ways in tropical developing countries. For instance, if there is a provision of adequate off-farm employment opportunities in the rural areas, rural to urban migration and a shift in energy requirements from wood based to other alternatives such as fossil fuels [38]. Previous empirical evidences found a positive relation between the per capita income and rate of deforestation [9, 28].

(vi) GDP growth

It is hypothesized that growth of an economy is accelerated by export of agricultural and forest derived products that causes deforestation, and when the economy starts growing, it also catalyses these exports. Thus, cause-effect relationship between these two is confusing over time and would lead to an econometric problem of *simultaneity*. Although this is a problem of cross sectional studies only, but for the time series studies, an increase in annual growth rate could lead to an increase in export [26]. Further, the effects of GDP per capita and GDP growth on deforestation should not be in the same direction [3]; they may vary, in particular, in the long run.

(vii) Debt as percentage of GNP

Foreign debt is sometimes used in the literature as one of the main causes of deforestation. Kahn and McDonald [25] hypothesized the link between debt and deforestation as a myopic behavior in the sense that causing excessive deforestation in the short run may be necessary to meet current constraint and past obligations. Capistrano and Kiker [9] hypothesized the same by currency devaluations, that the devaluations, introduced as part of the structural adjustment programs, would promote the exports of forest and agricultural products but with an increased rate of deforestation. Debt is considered as an explanatory variable in the models because still most of the developing countries have substantial foreign debt and they service their debt through the export of forest and agricultural products. Debt as percentage of GNP (instead of debt service ratio to total export earnings) is used because of data availability for the period under study.

(viii) Export price index

The evidence for the effect of export prices on deforestation remains controversial. It is expected that higher agricultural and timber prices resulting from the trade liberalization and currency devaluation would in general increase forest clearing [3].[6] According to scarcity hypothesis, however, an effect of a price increase would be more deforestation in short-run, but in a long-run the higher price may provide incentives to conserve the forests rather than to deplete, so that the net effect on deforestation would be negative [Rudel, p. 539].[7] Since export takes place from one country to many countries and also with different types of forest and agricultural products, it is difficult to specify one export price of these products for each country. Further, conversion of forestland to pasture is concentrated more in Latin American countries than in Africa and Asia, where large-scale cattle ranching operations are driven for the purpose of meat export [44]. Because of the emphasis given for the meat export, in addition to the forest products export, we use export price index (EPI) as a proxy for the export prices for the Latin American countries. The EPI is a derivation based on prices for individual commodities [23].

For the African and Asian countries, due to non-availability of data on EPI for the entire study period and all the countries, we calculated an industrial round wood price index (IRWPI) based on unit export value of industrial round wood, since industrial round wood consists most of the forest products exported from these countries (*www.fao.org*). First, the unit export

[6] This contradicts the claim that structural adjustment and trade liberalization policies will in general contribute to both economic and environmental gains i.e., a win-win situation as advocated by the World Bank and others [32].

[7] Some times higher export price can have an indeterminate effect on deforestation in the long run, depending on the net effect whether forest depletion or forest conservation takes place more. This argument is also based on the assumption that there are no effective substitutes for wood and other forest products.

value has been calculated using data on total value of export and total quantity of industrial round wood products. Then it has been converted into constant US$ using 1995 as the base year.

(xi) Time trend (technological change)

Time trend is used as a proxy for the other exogenous time dependent variables (such as technological change in agriculture). Angelsen and Kaimowitz [3] suggest that if a technological change in agriculture is labour- and/or capital-saving, it may free up more resources for additional farming and clear more forestland. But if it is more labour- and/or capital-intensive, it may not likely to leave resources for additional farming and contribute to less deforestation. Based on their review of more than 140 economic studies on deforestation, they, however, find no conclusive empirical evidence for the effect of technological progress on deforestation, and, therefore, the sign of the coefficient of time trend can not be predicted *a priori*.

Details of the variables, their explanation, units, sources and the expected relationship with deforestation are all summarized in Table 1.

(c) Environmental Kuznets Curve relationship

Further, the relationship between rate of deforestation and GDP per capita validates also the presence or absence of an EKC relationship in the forest sector. The concept of Kuznets curve originally proposed for an inverted U-shaped relationship between income growth and income inequality by Kuznets [29]. This concept, however, is recently being used to build the same relationship between income growth and environmental degradation, which has become known as the environmental Kuznets Curve (EKC). The EKC approach links environmental degradation (or protection) to the level of economic development of a country or region with respect to selected environmental indicators [18] including the rate of deforestation [6, 12, 27, 39]. A theoretical exploration of an EKC for deforestation is provided in Lopez [30].

The empirical literature on EKC for deforestation is still limited and provides mixed results. Studies in this literature have found some evidences for existence of an EKC for deforestation. But these findings vary significantly because of different usage of deforestation variable (annual rate of deforestation or rate of change in forest cover), type of data (cross-sectional or panel data), period of analysis, estimation technique (pooled or fixed- and/or random effects), form of dependent variable (level or log), exchange rate basis for GDP (market or purchasing power parity), functional form of regression equation (with or without a cubic term of GDP variable), and other explanatory variables included in the models [41, 42].

4. Econometric Models and their Estimation

In our empirical models, the dependent variable is *rate of deforestation* (DEF), which is defined as annual percentage change in forest area. The linear specification of all the variables (dependent and independent), listed in Table 1 above, provides results that can be interpreted directly as correlations, except for the quadratic term of the variable GDP per capita to validate the EKC hypothesis. Since our analysis uses a panel data method involving cross-sectional and time series data, we incorporate the individual country effects by α_{it}, and the time trend by TT. The coefficients of variables are given by βs and the error term is by ε_{it}. Based on these criteria and subject to governmental policies in different regions of the world, we specify the following two empirical models of deforestation relationship:

$$DEF_{it} = \alpha_{it} + \beta_1 AFA_{it} + \beta_2 PFA_{it} + \beta_3 POPDEN_{it} + \beta_4 API_{it} + \beta_5 GDPPC_{it} + \beta_6 (GDPPC_{it})^2 + \beta_7 GDPG_{it} + \beta_8 DEBT_{it} + \beta_9 EPI_{it} + \beta_{10} TT + \varepsilon_{it}$$

(*Model 1*)

We estimate *Model 1* only for Latin America. But for Africa and Asia we apply variable IRWPI (instead of variable EPI) and accordingly the following one becomes a different empirical model of deforestation relationship:

$$DEF_{it} = \alpha_{it} + \beta_1 AFA_{it} + \beta_2 PFA_{it} + \beta_3 POPDEN_{it} + \beta_4 API_{it} + \beta_5 GDPPC_{it} + \beta_6 (GDPPC_{it})^2 + \beta_7 GDPG_{it} + \beta_8 DEBT_{it} + \beta_9 IRWPI_{it} + \beta_{10} TT + \varepsilon_{it}$$

(*Model 2*)

The panel data analysis applied here facilitates identification of the net impact of the causes on deforestation. The advantages and limitations of using the panel data methods can be found in Baltagi [5] and Hsiao [21]. The standard deviations of the selected variables used in the crosscountry comparison are shown in Table 4 under Appendix 1. Multicollinearity is not a problem for the variables in the crosscountry samples of the three regions.[8]

Simple pooled regression, as well as fixed effects and random effects versions were tested to estimate the parameter values of both *Model 1* and *Model 2*. Preliminary investigation from *Model 1* (for Latin America) shows that the fixed effects version of this model performs better than its constant intercept version as can be evidenced by the F-test. Also, the random effects version of *Model 1* performs better than its constant intercept version in terms of the LM test. However, according to the Hausman test, the random effects version of *Model 1* is favored over its fixed effects version.[9] The constant intercept and the fixed effects versions of *Model 1* are homoscedastic and nonautocorrelated and, therefore, are estimated by the OLS method, while its random effects version is estimated by the two step GLS procedure.

The use of observations that are aggregation over varying number of countries is likely to give rise to heteroscedasticity problem in the OLS estimation and render its estimates of both the constant intercept and the fixed effects versions inefficient. Since we have favored the random effects version of *Model 1* and applied GLS method to obtain efficient estimates, we need to correct only autocorrelation and, therefore, we have applied AR1 correction following the Cochrane-Orcutt iterative procedure.

From *Model 2* (for Africa and Asia), the preliminary investigation shows that its fixed effects version performs better than its constant intercept and random effects versions. However, the OLS estimates of its fixed effects version have been corrected for heteroscedasticity and autocorrelation.[10] The parameter estimates after eliminating autocorrelation are found not to vary from that of the initial ones for both Africa and Asia. But the parameter estimates after eliminating heteroscedasticity are found to vary substantially from that of the initial ones for both the regions. For this reason we rely on parameter estimates of the fixed effects version corrected for heteroscedasticity.[11] Thus, unlike the previous studies[12], our study corrects for both heteroscedasticity and autocorrelation together.

5. Regression Results and Analyses

The final results of panel data analysis for the three regions are given in Table 2. The results we discuss are only based on the countries considered under each region (see Table 3 under Appendix 1) and therefore they should be interpreted cautiously. We discuss first on each of the underlying/policy-oriented causes of deforestation and then on the income-deforestation relationship (EKC) for the three regions.

(a) The underlying/policy-oriented causes of deforestation

Since there is no direct link between deforestation and policy variables, establishing a relationship between them may result in low explanatory power (i.e. R^2) of a regression analysis.[13] Previous cross-country econometric

[8] There is high collinearity between GDP per capita and its quadratic term as one would expect with polynomial regressions. Otherwise, only the correlation coefficient between AFA and GDP per capita is relatively high for Latin America, and the same between API and TT is relatively high for Africa and Asia.

[9] For detailed procedures related to the different statistical tests, one can see Greene [17].

[10] Following Breuch-Pagan test for heteroscedasticity, White correction applied to eliminate the heteroscedasticity. Similarly, following Durbin-Watson statistics, Prais-Winston iterative procedure applied to eliminate the autocorrelation.

[11] The Asian sample consist relatively small number of cross sectional units than the African sample. For these reason equal error variances within the groups assumed for the Asian sample when correcting for the heteroscedasticity.

[12] For example, some of the previous studies correct only hereroscedasticity [6] or only autocorrelation [12].

[13] The R^2 of estimated models for Latin America, Africa and Asia are 15.02, 25.11 and 20.25, respectively. The low R^2 values seem to be due the broader definition of deforestation, which includes both area of forest and woodlands. But this is the only available data source for a time-series analysis.

analyses, particularly based on the *FAO Production Yearbook* data on deforestation, report relatively low R^2 [6, 12]. The results drawn from such studies are, however, mostly useful to compare the direction and the relative magnitude of effect of the different policy variables across the regions. Further, the deforestation process varies across countries and regions, because the agents of deforestation make decisions for complex reasons and conditions which vary over time. Considering the variation of deforestation process, historical differences and institutional changes across the regions, our econometric models of deforestation are estimated to capture the similarities that may exist across the regions. Let us now look at the results related to the individual explanatory variables and their policy implication.

(i) Absolute forest area (FCGA) and proportion of forest area (CAFP)

The effect of absolute forest area (FCGA) is found to be positive for Latin America and Africa, while negative for Asia (although not significant). In contrary, proportion of forest area (CAFP) is found to be negative for Latin America and Africa while positive for Asia (although not significant). The results may imply that for Latin America and Africa the forest products export promotion policies are less likely to affect deforestation than the forestry sector and allied (non-forest sector) policies. Hence, appropriate policy interventions are needed in the forestry and the allied sectors. Such policy prescriptions should also be based on specific objective of individual countries.

(ii) Agricultural production and technological change

The effect of agricultural production (API) is positive for Latin America and negative for Africa. The positive effect may imply expansion of cropland into forests. Evidences suggest that in tropical Latin American countries landless peasants convert forest to grow crops for subsistence needs, while commercial farmers do the same for export crops [11]. Globalisation and economic liberalization increase global demand for agricultural and forest products in addition to the demand faced at national and regional levels. This new prospects for exports may lead for rapid deforestation in countries where small domestic markets previously limited deforestation process [3]. This would be the case for certain Latin American countries like Brazil, Bolivia and Paraguay where forest has been cleared for soybean export [Miranda *et al* cited in 11].

The negative sign of time trend for all the three regions (although only significant for Latin America) indicates that technological progress in agriculture would reduce deforestation. The results may imply that land intensifying technologies by increased application of labour, hybrid seeds, fertiliser and irrigation may be facilitated by agricultural research and extension policies to reduce the expansion of cropland into forests. But in reality these technologies are mostly accessible by commercial (big) farmers; small farmers (peasants) often have very limited access to such technologies and the complementary inputs they require [Bilsborrow and Geores, p.11]. The question is then what policy incentives are to be adopted in order to meet the requirements of the small farmers. Under the structural adjustment and liberalization programmes, it is increasingly emphasised that subsidies for agricultural inputs such as fertiliser, chemicals and credit should be removed. In many countries the reforms have been a controversial issue with respect to their likely impacts on deforestation and land degradation [34].

(iii) Population density

The positive effect of high population density for Africa suggests for increased demand for wood consumption and agricultural land expansion [26]. In Africa, peasants and fuel wood collectors are the main agents of deforestation, particularly in dry areas of Sahal [11]. Thus stronger policies for population control, off-farm employment opportunities to keep people away from clearing forests, re-/af-forestation programs to meet the growing demand for wood, secure land tenure policies and adequate means to increase the lands productivity for intensive farming systems are appropriate.[14] The effect of population density, however, can not be a cause by it self. The effect is endogenous at local and regional levels and decided by infrastructure availability, soil quality, distance to markets, off-farm

[14] Studies also find relationship between the population growth and deforestation, but the results are indeterminate [12, 22, 26, 36].

employment opportunities, and other factors. Certain government policies such as road construction, colonization, agricultural subsidies and tax incentives also influence migration of people into forests. The implications of such policies are that they are the actual causes of deforestation than the population growth per se [3].

(iv) GDP per capita and GDP growth

The effect of GDP per capita on deforestation is positive for Latin America and Africa, while negative for Asia. But the effect of GDP growth is negative for Latin America and Africa (although not significant for Africa), while positive for Asia. The results suggest that, particularly in the long run, GDP per capita and GDP growth affect deforestation differently.[15] Other studies also show the effect of GDP per capita in both directions [6, 9, 12, 27, 28], but the effect of GDP growth is negative [12, 27].

The positive effect of GDP per capita may imply that, for Africa, nearly 70 percent of total energy requirement of the Sub-Sahara Africa is provided by wood. Fuel wood collectors are accounted for over 85 percent of wood removed from the forest and woodland in this region. The negative effect of GDP per capita for Asia might not, however, imply that wood consumption is not an active source of deforestation. The fact is that the role of fuel wood collectors is also significant in this region [11], but the Asian countries have implemented strong policies towards reforestation and regeneration of the deforested areas.[16] The positive effect of GDP growth for Asia may imply that forest product export is the main source of deforestation in Asia [Kant and Redantz, p. 70]. Generous timber concession policies and low royalties are common in Southeast Asia, and favoured by the states to encourage loggers for timber export [2].

(v) External debt (debt as percentage of GNP)

Previous studies show a positive effect of debt on deforestation [6, 9, 25, 26]. Political economy of managing debt and environmental problems are somewhat complicated. It is argued that debt and environmental problems have the same root causes of general economic mismanagement, misguided policy for rapid (and unsustainable) economic growth, public sector mismanagement, and elitist behavior and corruption. These factors lead to a level of foreign borrowing that can not be sustained[17], particularly when the borrowed resources are not invested productively. Environmental degradation can thus be a result of the drive for quick economic growth [40]. Our results also show a positive effect of debt on deforestation for all the three regions, although they are statistically not significant.

(vi) Export prices (EPI and IRWPI)

According to our result, export price affects deforestation negatively for all regions, although statistically significant only for Latin America. The negative effect may imply that an export price increase would reduce deforestation (in a long-run), and conserve forest resources. Effect of export price on deforestation, however, is a controversial issue. For example, a cross-country study by Capistrano and Kiker [9] shows positive effect of export price on deforestation for the period of 1967-1971, but negative effect for the period of 1976-1980.

(b) Environmental Kuznets Curve (EKC)

In our empirical analysis, we find an inverted U-shaped curve for Latin America and Africa, while a U-shaped curve for Asia. The turning point for Africa at US$ 6072 is, however, much higher than the turning point for Latin America at US$ 1483. The turning point for Africa is also much higher than

---

[15] Usually one might expect that in a short- or medium-term, GDP per capita and GDP growth would affect deforestation in the same direction.

[16] For example, country like India followed a strong policy to reforest and to allow for regeneration of the deforested areas since 1950s [10].

[17] Often, debt service consumes a larger share of income and foreign exchange earnings, thereby squeezing out the investments needed for public programs including environmental protection. However, opportunities for debt-for nature swaps [14, 19] may help the countries to escape from the constraint imposed by heavy debt burden. Debt management in form of debt-for-nature swaps is increasingly being practiced as a means to relieve debt burden and to conserve endangered tropical forests [6].

the current value of GDP per capita for many of the African countries in our sample. This may imply that major damage to forest may occur in these African countries well before this point is reached. For Asia, the turning point at US$ 2320 indicates that countries with income up to this level have a decreasing rate of deforestation. The U-shaped curve for Asia may also imply that even natural forest clear-cutting is prevalent in this region, particularly for Southeast Asian countries, reforestation is greater in Asia than Latin America and Africa [6, 12].[18]

Only a few other studies have used panel data method to estimate the EKC relationship of deforestation for Latin America, Africa and Asia [6, 12, 27].[19] Of these, Cropper and Griffiths's [12] fixed effects model has found the EKC fit for Africa with turning point at US$ 4,760 and Latin America with turning point at US$ 5,420. Using similar variables of Cropper and Griffiths [12], Koop and Tole [27] have estimated the EKC with constant term pooled regression, fixed effects, random effects and random coefficients models. Their Kuznets curve appears to fit only for Latin America with a turning point at US$ 8660, which is much higher than that of Cropper and Griffiths [12]. Bhattarai and Hammig [6] have estimated the EKC for all three regions by fixed effects models, but with a cubic term, resulting in an N-shaped curve for Latin America and Africa, and an inverted N-shaped curve for Asia. In comparison with these earlier studies, our estimates are somewhat different. Unlike the existing EKC literature on deforestation, we find a statistically significant U-shaped EKC for Asia.

The inverted U-shaped EKC for Latin America and Africa may imply that current level of economic development in the regions does not seem to reverse the current rate of deforestation. In addition to increased level of economic development, better agricultural and forestry policies may play a greater role in limiting the rate of deforestation. Such policies should be targeted towards increased agricultural productivity, off-farm employment opportunity, land reform with tenure/ownership, and re-forestation as well as afforestation programs. The overall implication of the EKC (inverted U-curve) is that some form of deforestation is inevitable during the early stage of development. However, the rate of deforestation could be minimized at the later stage of development with the incentives provided by the development process itself, although within the ecological threshold (irreversibility) limit of the forests.

[18] According to the FAO estimates in 1990, the natural forest area in Asia decreased by 3.9 million hectare, but nearly 2.1 million hectares were planted , and that net decrease in the forest and woodland area is only by 1.8 million hectares [12].

[19] A review of the other studies on the EKC for deforestation can be found in Stern [42].

6. Conclusions and Policy Implications

The usefulness and validity of results obtained in previous studies of cross-country regression analysis are questioned from econometric and methodological points of view. In our study, we have made an attempt to respond to some of these questions by establishing relationships between rate of deforestation and its underlying/policy-oriented causes using data across 43 countries of Latin America, Africa and Asia over a period of 1971-94.

This study finds evidence that export promotion policies for forest products (CAFP) are less likely to influence deforestation than forestry and allied sector policies (FCGA). Thus the forestry and allied sector policies need to be strengthened for the Latin American and the African countries. The result that population density influences deforestation positively for Africa may imply that the African countries need to implement stronger re-/afforestation programs. Such programs can be expected to meet the growing demand for wood. On the other hand, off-farm employment opportunities, secure land tenure rights and population control could also help to reduce deforestation in this region.

The result that *agricultural production* influences deforestation positively for Latin America may suggest that appropriate technology is required for intensive and profitable farming systems. Because *export price* influences deforestation negatively for Latin America, an increase in export price may then reduce the rate of deforestation. Effects of export price on deforestation, however, need consideration for time span, because higher export price may provide incentive to conserve the forests in the long-run. The effects of *per capita income* and *economic growth* on deforestation are, however, ambiguous going towards either direction across the regions.

Inverted U-shaped EKC for both Latin America and Africa, with its relatively higher turning point at a higher level of per capita income, suggests that major damage to forest may occur in some countries in these regions well before the turning point is reached. For Asia, the U-shaped EKC tends to imply that reforestation is greater, in spite of prevalence of natural forest clear-cutting in this region. Thus, for the African and the Latin American countries, along with higher level of economic development, improving the agricultural and forestry policies may play a greater role in combating deforestation.

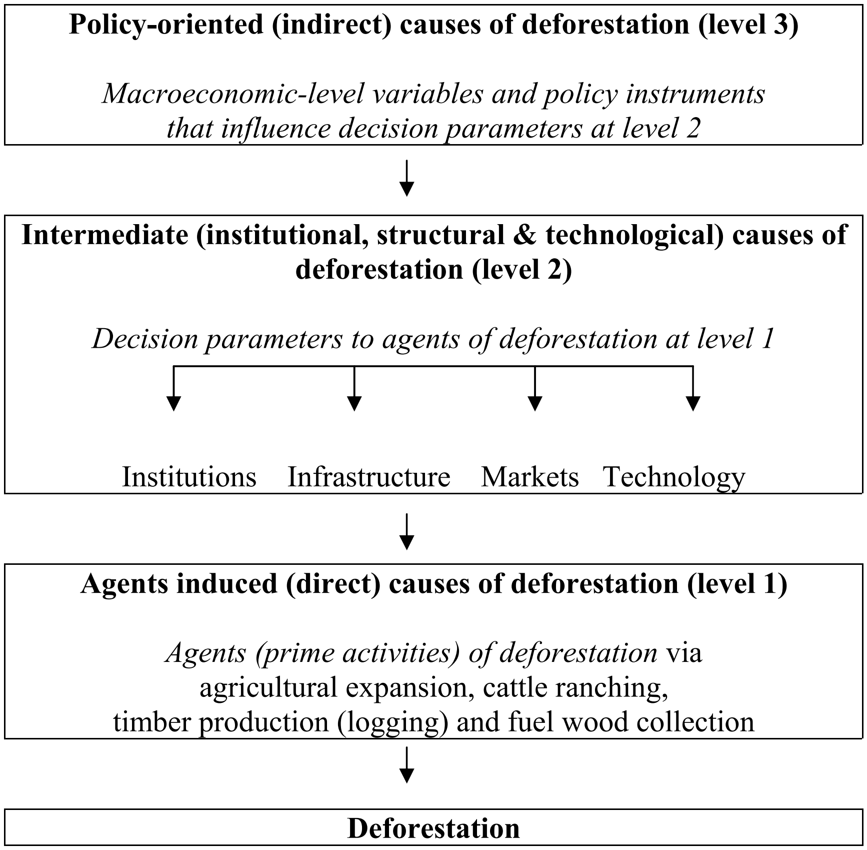
The overall implication of the results in our present study implies that the underlying/policy-oriented causes leading to deforestation differ somewhat across the regions and therefore there is a need for specific policy recommendation for restraining the deforestation process of different regions.

7. References

1. J. C. Allen and D. F. Barnes, The causes of deforestation in developing Countries, *Annals of the Association of American Geographers*, **75**, 163-184 (1985).
2. A. Angelsen and R. Culas, Debt and deforestation: a tenuous link, Christian Michelsen Institute (CMI), Norway, Working Paper No. 10, 1996.
3. A. Angelsen D. Kaimowitz, Rethinking the causes of deforestation: lessons from economic models, *The World Bank Research Observer*, **14**, 73-98 (1999).
4. A. Angelsen, E. F. K. Shitindi and J. Aarrestad, Why do farmers expand their land into forests? theories and evidence from Tanzania, *Environment and Development Economics*, **4**, 313-31 (1999).
5. B. H. Baltagi, Econometric analysis of panel data, New York: Wiley, 1995.
6. M. Bhattarai and M. Hammig, Institutions and the environmental Kuznets Curve for deforestation: a cross-country analysis for Latin America, Africa and Asia, *World Development*, **29**, 995-1010 (2001).
7. R. Bilsborrow and M. Geores, Population, land-use and the environment in developing countries: what can we learn from cross-national data?, in "The causes of tropical deforestation: the economic and statistical analysis of factors giving rise to the loss of the tropical forests" (K. Brown and D. Pearce, Eds.), UCL Press, London, 1994.
8. K. Brown and D. Pearce (Eds.), The causes of tropical deforestation: the economic and statistical analysis of factors giving rise to the loss of the tropical forests, UCL Press, London, 1994.
9. A. D. Capistrano and C. F. Kiker, Macro-scale economic influences on tropical forest depletion, *Ecological Economics,* **14**, 21-29 (1995).
10. M. Chakraborty, An analysis of the causes of deforestation in India, in "The causes of tropical deforestation: the economic and statistical analysis of factors giving rise to the loss of the tropical forests" (K. Brown and D. Pearce, Eds.), UCL Press, London, 1994.
11. A. Contreras-Hermosilla, The underlying causes of forest decline, Centre for International Forestry Research (CIFOR), Indonesia, Occasional Paper No.30, 2000.
12. M. Cropper and C. Griffiths, The interaction of population growth and environmental quality, *American Economic Review*, **84**, 250-254 (1994).
13. F. Ellis, Peasant economics, Cambridge University Press, U.K, 1993.
14. Z. Fabio, Tropical deforestation: debt-for-nature versus debt-for-development swaps, *Environment and Development Economics*, **3**, 267-293 (1998).
15. Food and Agricultural Organization (FAO), Forest resources assessment, Tropical countries. Rome: FAO, Forestry Paper No. 112, 1992.
16. Food and Agricultural Organization (FAO), State of the world's forests, Rome: FAO, 1997.
17. W. H. Greene, Econometric analysis, Prentice Hall, NJ, USA, 1993.
18. G. M. Grossman A. B. Krueger, Economic growth and the environment, *Quarterly Journal of Economics*, **112**, 353-378 (1995).
19. S. Hansen, Debt for nature swaps: overview and discussion of key issues, *Ecological Economics,* **1**, 77-93 (1989).
20. R. A. Houghton, The role of the world's forest in global warming, in "The World Forests for the Future" (K. Ramakrishna and G. M. Woodwell, Eds.), New Haven: Yale University Press, 1993.
21. C. Hsiao, Analysis of panel data, Cambridge: Cambridge University Press, 1986.
22. K. Inman, Fuelling expansion in the third world: population, development, debt, and the global decline of forests, *Society and Natural Resources,* **6**, 17-39 (1993).
23. International Monitory Fund (IMF), International financial Statistics yearbook, Washington DC: IMF, 2000.
24. B. Johnson, Responding to tropical deforestation: an eruption of crisis and array of solutions, London: Conservation Foundations, 1991.
25. J. R. Kahn and J. A. McDonald, Third-World debt and tropical deforestation, *Ecological Economics,* **12**, 107-123 (1995).

26. S. Kant and A. Redantz, An econometric model of tropical deforestation, *Journal of Forest Economics* **3**, 51-86 (1997).
27. G. Koop and L. Tole, Is there an environmental Kuznets Curve for deforestation?, *Journal of Development Economics,* **58**, 231-244 (1999).
28. K. Kurtilla, W. F. Hyde D. F. Barnes, Urban energy consumption and periurban deforestation, *Forest Ecology and Management,* **74**, 181-195 (1995).
29. S. Kuznets, Economic growth and income inequality, *American Economic Review*. **45**, 1-28 (1955).
30. R. Lopez, The environment as a factor of production: the effects of economic growth and trade liberalization, *J. Environ. Economics and Management*, **27**, 163-184 (1994).
31. M. Miranda, A. Q. Blanco-Uribe, L. Hernandez, J. Ochoa, and E. Yerena, All that glitters is not gold. Balancing conservation and development in Venezuela's frontier forests, Washington, D. C: World Resources Institute, 1998.
32. M. Munasinghe and W. Cruz, *Economy wide policies and the environment: lessons from experience*. Washington, D. C: World Bank, Environment Paper 10, 1995.
33. M. Palo, Population and deforestation, in "The causes of tropical deforestation: the economic and statistical analysis of factors giving rise to the loss of the tropical forests" (K. Brown and D. Pearce, Eds.), UCL Press, London, 1994.
34. D. Reed (Eds.), Structural adjustment, the environment and sustainable development, London: Earthscan Publications Ltd, 1996.
35. R. Repetto, The forest for the trees: government policies and the misuses of forest resources, Washington D.C: World Resource Institute, 1988.
36. M. T. Rock, The stork, the plow, rural social structure and tropical deforestation in poor countries? *Ecological Economics,* **18**, 113-131 (1996).
37. T. Rudel and J. Roper, The paths to rain forest destruction: cross-national patterns of tropical deforestation 1975-90, *World Development,* **25**, 53-65 (1997).
38. K. T. Rudel, Is there a forest transition? deforestation, reforestation, and development, *Rural Sociology*, **63**, 533-552 (1998).
39. N. Shafik, Economic development and environmental quality: an econometric analysis, *Oxford Economic Papers*, **46**, 757-773 (1994).
40. J. D. Shilling, Reflections on debt and the environment, *Finance and Development,* June: 28-30 (1992).
41. D. I. Stern, M. S. Common and E. B. Barbier, Economic growth and environmental degradation: the environment Kuznets Curve and sustainable development, *World Development*, **24**, 1151-1160 (1996).
42. D. I. Stern, Progress on the environmental Kuznets Curve?, *Environment and Development Economics,* **3**, 173-196 (1998).
43. S. R. Templeton and S. J. Scherr, Effects of demographic and related microeconomic change on land quality in hills and mountains of developing countries, *World Development*, **27**, 903-918 (1999).
44. L. Tole, Sources of deforestation in tropical developing countries, *Environmental Management,* **22,** 19-33 (1998).
45. World Bank, The forest sector (a policy paper), Washington DC: World Bank, 1991.
46. World Bank, World development indicators, Washington DC: World Bank, 2000.
47. World Commission on Environment and Development (WCED), Our common future, Oxford: Oxford University Press, 1987.

FIGURE 1: VARIABLES AFFECTING DEFORESTATION



Source: Modified after Angelsen and Kaimowitz [3].

Table 1: Details of Variables

Variable	Explanation	Unit	Source	Expected sign
DEF	Rate of deforestation	Percentage	www.fao.org	
AFA (FCGA)	Absolute forest area	1000 ha	www.fao.org	Positive
PFA (CAFP)	Proportion of forest area	proportion	www.fao.org	Positive
API	Index of agricultural production	Base period 1989-91	www.fao.org	Positive
POPDEN	Population Density	People per hectare	www.fao.org	Positive
GDPPC	GDP per capita	1000 US$ (1995)	World Bank (WDI 2000)	Positive
$GDPPC^2$	GDP per capita squared			Negative
GDPG	Annual rate of growth	Percentage	World Bank (WDI 2000)	Positive
DEBT	Percentage of GNP	Percentage	World Bank (WDI 2000)	Positive
EPI	Export price index	Base year 1995	IMF (IFS 2000)	Negative
IRWPI	Industrial round wood export price index	Base year 1995	www.fao.org	Negative
TT	Time trend			No prediction

Table 2: Variables Affecting Rate of Deforestation, 1971-94[@]

Independent Variable	Latin America (model 1) Random effects model	Africa (model 2) Fixed effects model	Asia (model 2) Fixed effects model
AFA (FCGA)	0.345×10^{-5} ** (0.170×10^{-5})	0.261×10^{-3} *** (0.973×10^{-4})	-0.942×10^{-4} (0.830×10^{-4})
PFA (CAFP)	-4.239 *** (1.103)	-74.864 *** (23.087)	-6.777 (12.952)
API	0.213×10^{-1} *** (0.286×10^{-2})	-0.113×10^{-1} * (0.649×10^{-2})	-0.126×10^{-1} (0.201×10^{-1})
POPDEN	0.183×10^{-1} (0.332×10^{-1})	1.648 * (0.930)	-0.963 (1.565)
GDPPC	0.967 *** (0.301)	1.603 ** (0.637)	-3.568 * (1.857)
$GDPPC^2$	-0.326 *** (0.538×10^{-1})	-0.132×10^{-1} ** (0.542×10^{-1})	0.769 ** (0.374)
GDPG	-0.140×10^{-1} *** (0.424×10^{-2})	-0.719×10^{-2} (0.879×10^{-2})	0.936×10^{-1} *** (0.308×10^{-1})
DEBT	0.369×10^{-2} (0.324×10^{-2})	-0.780×10^{-2} (0.223×10^{-1})	0.434×10^{-1} (0.590×10^{-1})
EPI	-0.172×10^{-3} *** (0.370×10^{-4})	-	-
IRWPI	-	-0.360×10^{-4} (0.128×10^{-3})	-0.924×10^{-3} (0.865×10^{-3})
TT	-0.454×10^{-1}) *** (0.659×10^{-2})	-0.114×10^{-1}) (0.127×10^{-1})	-0.798×10^{-2} (0.417×10^{-1})

APPENDIX 1

Table 3: List of countries used in the analysis (with years of data availability)

Africa	Asia	Latin America
Angola (85-94)	Bangladesh (92-94)	Bolivia (84-94)
Benin (91-94)	Cambodia (87-94)	Brazil (71-94)
Cameroon (71-94)	India (71-94)	Colombia (71-94)
C.African Republic (71-94)	Indonesia (71-94)	Dominican Republic (71-94)
Congo Democratic Republic (71-94)	Malaysia (71-94)	Ecuador (71-94)
Congo Republic (71-94)	Papua-New Guinea (71-94)	Guyana (71-94)
Cote d'Ivore (71-94)	Philippines (71-94)	Honduras (75-94)
Eq. Guinea (85-94)	Solomon Island (78-94)	Jamica (71-94)
Gabon (71-94)	Sri Lanka (71-80; 90-94)	Peru (71-94)
Ghana (71-94)	Thailand (71-82; 90-94)	
Guinea (86-94)	Viet Nam (85-94)	
Kenya (78-84; 90-94)		
Madagascar (71-94)		
Malawi (71-79;90-94)		
Mozambique (81-93)		
Nigeria (71-94)		
Rwanda (91-94)		
Senegal (93-94)		
Sierra Leone (92-94)		
Tanzania (89-94)		
Togo (90-94)		
Zambia (90-92)		
Zimbabwe (76-94)		

Table 4: Descriptive statistics of variables in the study, by region, 1971-94

Variable	Latin America	Africa	Asia
Deforestation rate (annual %)			
Mean	0.19	0.17	0.33
SD	0.80	1.18	1.93
Total forest area (1000 ha)			
Mean	90726.22	29635.96	35813.48
SD	172098.88	41677.81	36578.66
Proportion of forest area			
Mean	0.51	0.47	0.55
SD	0.23	0.22	0.25
Population density (people per ha)			
Mean	2.82	0.30	1.25
SD	4.47	0.34	1.31
Agricultural production index			
Mean	91.75	87.30	85.73
SD	20.64	16.32	19.10
GDP per capita (US$1,000s)			
Mean	1.72	0.80	0.94
SD	0.99	1.24	0.78
GDP growth rate (annual %)			
Mean	3.28	2.21	5.26
SD	5.01	7.56	4.36
Debt (percentage of GNP)			
Mean	9.28	5.63	5.43
SD	10.05	4.99	4.18
Export price index			
Mean	188.01	-	-
SD	600.91	-	-
Industrial roundwood price index			
Mean	-	136.13	221.02
SD	-	236.42	290.91
Number of countries	9	23	11
Number of observations	199	330	190