Deforestation and Forest-Induced Carbon Dioxide Emissions in Tropical Countries: How Do Governance and Trade Openness Affect the Forest-Income Relationship?

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The objective of this article is to study the implications of changes in land use induced by economic growth, economy-wide policies, and governance on deforestation and forest-induced atmospheric carbon dioxide emissions. Economic growth, democracy, and trade policy explain an important share of the variation in two key determinants of deforestation: agricultural expansion and road building. The resulting shape of the Environmental Kuznets Curve for forests is influenced by governance as well as trade openness. Trade shifts the forest-income curve up (down) for countries that have a comparative disadvantage (advantage) in the production of crops encroaching on forest areas, such as Brazil and the Philippines (Indonesia and Malaysia). A more democratic country will have a farther turning point than a less democratic country, but whether the Environmental Kuznets Curve shifts up or down is country specific.

Keywords: *Environmental Kuznets Curve; deforestation; governance; trade policy; carbon dioxide emissions*

A significant part of greenhouse gas (GHG) emissions in developing countries is associated with land use changes. This is in contrast to developed countries, where most GHG emissions originate in the industrial and transportation sectors. Forest conversion to agriculture as well as to other uses is among the most important sources of GHG caused by changes in land use, especially in tropical forest-rich countries. Tropical forests retain large volumes of biomass per hectare (ha). Land clearing, which often causes the burning of the forest biomass, leads to net emissions of carbon dioxide and other GHGs. Existing studies provide estimates of carbon dioxide retention by standing tropical forests, ranging from 100 to 250 metric tons per hectare (Crutzen & Andreae, 1990;

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Naughton-Treves, 2004). A large portion of stored carbon dioxide is released into the atmosphere when forests are cleared.

The objective of this article is to study the implications of changes in land use induced by economic growth, certain economy-wide policies, and governance on deforestation and carbon dioxide emissions. The key questions addressed by this study are as follows: Does an Environmental Kuznets Curve depicting the relationship between per capita income and forest cover exist?[1] If such a curve exists, at what income level does the turning point occur? How do governance, trade openness, and other government policies affect the level and turning point of the forest-income relationship? How do changes in forest cover affect carbon dioxide emissions? How are deforestation-induced emissions affected by per capita income, governance, and trade openness?

Earlier studies have attempted to estimate reduced-form relationships between per capita income and deforestation using cross-country data from the Food and Agriculture Organization (FAO) on forest area (Barbier & Burgess, 2001; Cropper & Griffiths, 1994). In general, they have found the existence of an environmental Kuznets relationship with turning points not too far from the current levels of per capita income of middle-income developing countries.

However, these studies have important limitations: (a) Data on forest area throughout time produced by the FAO are interpolations based on 1 or 2 years of actual data at the most. To construct annual series, the FAO interpolates data by using population growth and per capita income variables among others. (b) The estimates are reduced form in nature and fail to control for policies and institutions.[2] Given the potential significance of these omitted variables on deforestation and their correlation with per capita income, omitted variable biases on the estimated coefficients associated with income are likely to occur.[3] (c) The omission of policy variables may not only bias the income coefficients but also precludes understanding the interactions between policies and per capita income in shaping the forest-income relationship.

Democracy and governance can affect the quantity and quality of public goods that the state provides (Deacon, 2000). Among these public goods, the provision of environmental regulation, enforcement, and property right institutions are vital factors that determine environmental performance. An important issue is whether better governance and

1. An Environmental Kuznets Curve for forest cover would suggest a U-shaped rather than an inverted-U–shaped relationship, as is the case with pollutants.

2. If a pure causal effect from income to policies and institutions exists, it would not be a problem. However, this is often not the case. Studies have shown that institutions and policies have their own independent dynamics (Ferreira, 2004). Their changes throughout time may be correlated with income, but much of their changes are not caused by income.

3. Studies that control with fixed country effects in their regressions do not mitigate this problem because several policies and institutions do change with time.

more democracy can influence the effect of income on forests. Also, trade policy reform has been one of the most controversial policies implemented by many developing countries during the past two decades because of its potential negative impact on the environment.[4] An emerging consensus seems to be that the effect of trade policy on the environment is country specific, as it is driven by country characteristics, including comparative advantages and the initial level of trade openness (Copeland & Gulati, in press). This study provides new insights into this debate by comparing the impact of trade openness and governance on deforestation and carbon dioxide emissions resulting from deforestation across four different countries.

It is well known that road construction into forest regions is a key direct source of deforestation (Chomitz & Thomas, 2003). Yet there are few studies that look into the factors that induce governments to spend more or less resources in road-building expansion into forested areas (López & Galinato, in press). Moreover, the potential interdependences between agricultural expansion and road building into forest areas have not been studied in detail. We empirically examine how per capita income affects road building and how exogenous changes in road-building policies impinge on the forest-income relationship.

Once we derive the impact of government policies on deforestation, we then derive carbon emissions generated by deforestation, an issue barely considered in the literature on carbon emissions, which has focused mainly on industrial emissions. It is important to understand how income affects the flow of carbon dioxide emissions. Unlike industrial emissions, the level of income does not define the amount of deforestation-induced carbon emissions. This is because a level of income corresponds to a level of forest stock. Only when forest stock or area changes will we see a change in forest-induced carbon dioxide emissions. Thus, the rate of change of income, rather than the income level as in the industrial emissions, may be the key determinant of the amount of carbon dioxide emissions from deforestation. In fact, at the turning point of the forest-income curve, economic growth causes the country to change from a net emitter to a net absorber of forest carbon dioxide. Clarifying this issue and providing one of the first empirical estimates of it is an additional important contribution of this article, even if special assumptions are needed to offset data weaknesses.

We focus on the direct causes of deforestation as identified by microstudies of deforestation in various countries, which have used more precise data on deforestation than the existing macrostudies using FAO data on forests. The direct factors of deforestation identified by microstudies are mostly related to land use changes. In particular,

4. See Copeland and Taylor (2004) for an overview of the trade and environment literature.

microstudies have singled out agriculture area expansion and road building in forested regions as key sources of deforestation. Unlike the earlier macrostudies using aggregate data on deforestation as estimated by FAO, microstudies have measured the marginal impact of these two factors on forest cover using physical forest cover data by microregions obtained through surveys and remote sensing information.

Identifying and measuring the direct causes of deforestation have been significant steps in understanding deforestation. However, it is important to complement these findings with an analysis that will help us measure how these direct factors of deforestation are affected by income growth, economy-wide policies, and governance. We derive these new estimates and combine them with the existing micro-estimates. This allows us to establish a chain mechanism from per capita income and economy-wide policies to land use, from land use to forest area changes, and from forest area changes to carbon dioxide emission changes.

Using annual panel data for the period from 1975 to 1995, we study four tropical countries: Brazil, Indonesia, Malaysia, and the Philippines. Together, these countries compose 33% of the total remaining tropical forests in the world. On average, 62% of the total land area in these countries is covered by forests. Moreover, deforestation is a large source of carbon dioxide emissions. According to our estimates, carbon dioxide emissions from forest clearing during the 1990s accounted for 30% to 35% of total carbon dioxide emissions from all sources in Brazil. In Indonesia, Malaysia, and the Philippines, forest emissions amounted to 20% to 26%, 10% to 14%, and 6% to 9% of all emissions, respectively, during the same period.

Conceptual Model

Microstudies of deforestation have identified land use patterns as the most important source of deforestation (Chomitz & Thomas, 2003; Cropper, Puri, & Griffiths, 2001; Panayotou & Sungsuwan, 1994; Pfaff, 1999). There is consensus among the studies that expansion of agriculture and construction of roads into forest areas is the most important direct factor determining deforestation. Practically all economic activities that may induce deforestation depend on road construction along accompanying infrastructure into forest regions. Also, though agriculture area expansion is dependent on road and other infrastructure, it has its own dynamics by being significantly affected by factors other than road building as well. Logging may also have its own dynamics partly independent of road construction. However, the fact that initial logging is usually followed by agricultural production in the cleared areas

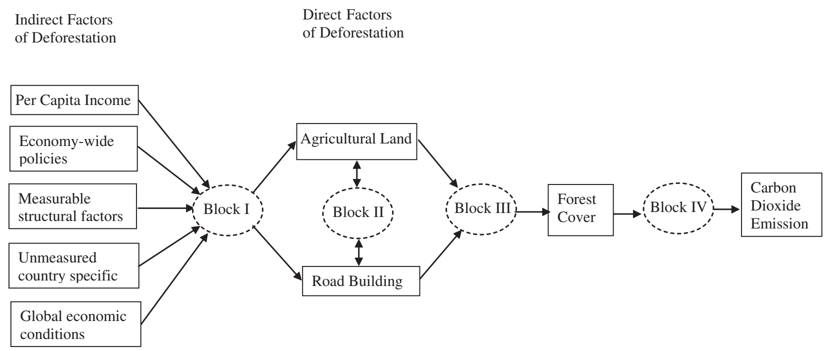

Figure 1: Linking Deforestation-Induced Carbon Emissions to Macroeconomic Variables

makes it difficult to separate the effect of logging from agricultural expansion.

Figure 1 describes the chain process that we consider in the analysis of the effects of per capita income and economy-wide policies on forest cover and, ultimately, carbon dioxide emissions from deforestation. Growth of per capita income and other macroeconomic changes (the indirect factors) affect agriculture area expansion and a country's financial capacity as well as the government's priorities to expand roads into forest regions (the direct factors). This, in turn, affects the economic incentives for forest clearing, causing changes in carbon dioxide emissions. There are four blocks of causation, represented by arrows, in Figure 1: Block 1 shows the effects from the indirect factors on the direct factors of deforestation; Block 2 shows the interdependent two-way causation between the two direct factors, agricultural land, and road building; and Block 3 shows the effects from the direct factors on forest cover. Finally, Block 4 relates changes in forest cover and carbon dioxide emissions. The ensuing model provides a conceptual framework to empirically measure Blocks 1, 2, and 3. Block 4 is measured separately using existing empirically estimated parameters of carbon dioxide releases associated with the clearing of various types of forests.

We postulate the following specification determining forest levels:

$$Forest = a_0 + a_1 crop + a_2 road + a_3 Z + \varepsilon_0 \tag{1}$$

where *Forest* is log of total tropical forest cover, *crop* is log of agriculture area in forest regions, and *road* is log of paved road. The coefficient a_0 reflects factors unrelated to agriculture and road building into forest regions, including natural conditions, such as climate, and other variables that determine the natural availability of forest in the first place.

The coefficients a_1 and a_2 are the marginal (proportional) effect of crop production and road network, respectively, on forest cover. The vector **Z** stands for variables that may influence forest cover independently from the influence of crop and roads.

Equation 1 is not estimated here, but the coefficients and its respective variances derived from existing microstudies of deforestation are used. What we do estimate are the determinants of crop area and roads into forest regions (causation Blocks 1 and 2 in Figure 1). The following specification of the road and crop equations allows for two-way causality between crops and roads:

$$crop_{it} = \alpha_{0,i} + \alpha_1 GDPPC_{it} + \alpha_2 GDPPC_{it}^2 + \alpha_3 DEM_{it} + \alpha_4 SATI_{it} + \alpha_5 road_{it} + \alpha_6 GDPPC_{it} \bullet SATI_{it} + \alpha_7 GDPPC_{it} \bullet DEM_{it} + AX_{1,it} + \alpha_{00,t} + \varepsilon_{1,it} \quad (2)$$

$$road_{it} = \beta_{0,i} + \beta_1 GDPPC_{it} + \beta_2 GDPPC_{it}^2 + \beta_3 DEM_{it} + \beta_4 SATI_{it} + \beta_5 crop_{it} + \beta_6 GDPPC_{it} \bullet SATI_{it} + \beta_7 GDPPC_{it} \bullet DEM_{it} + BX_{2,it} + \beta_{00,t} + \varepsilon_{2,it}. \quad (3)$$

Here, $GDPPC_{it}$ is log of GDP per capita in country i at year t, *SATI* is the trade openness index, *DEM* is an index of democracy, vector $\mathbf{X}_1$ is a set of all other variables that explain changes in crop production, vector $\mathbf{X}_2$ is a set of all other variables that explain changes in road networks, $\alpha_{0,i}$ and $\beta_{0,i}$ are the country fixed effects, $\alpha_{00,t}$ and $\beta_{00,t}$ are time effect dummy variables, and ε_{it} are random error terms. Vectors **A** and **B** are parameters associated with the variables in $\mathbf{X}_1$ and $\mathbf{X}_2$, respectively.

In Equations 2 and 3, we can distinguish five groups of factors that may affect agriculture and road expansion into forest regions: (a) the country's wealth, which can be represented by per capita income; (b) economy-wide policy-related variables, such as trade openness, openness to foreign capital, policies affecting macroeconomic disequilibrium proxy by exchange rate black market premium, fiscal deficits, and domestic inflation; (c) measurable structural factors, including democracy and governance; (d) unmeasured country-specific fixed factors; and (e) global economic conditions, including international commodity prices. Variables (b) are policies and factors that are closely linked to policies that vary throughout time and across countries. Variables (c) are country characteristics that also change throughout time and across countries but are affected by policies in an indirect way and tend to respond sluggishly to policies. Variables (d) are country-specific structural characteristics that change little, if at all, throughout time, such as climate, geographical conditions, and factor endowments. Variables (e) consider the impact of international shocks (e.g., international agricultural commodity prices and interest rates) that are likely to affect all countries at the same time.

Among the structural factors (c), we use an index of democracy and civil society participation in governance. Previous studies have shown that democratic and representative governments tend to supply more public goods, including better definition and enforcement of property rights (Deacon, 2003). Road construction is an important public good provided by the government. Democracy may not only induce a greater supply of roads, but it may also cause a change in the composition of road construction. A plausible hypothesis is that more democratic governments may be more responsive to community demands to intensify road building in already settled areas rather than give priority to extend road building into less populated areas, such as forest regions.[5] Thus, democracy may cause a greater budget for road building, but a smaller fraction of this budget goes to construction of roads in frontier or forest regions. Therefore, the net effect of governance or democracy on road building into frontier forest regions is ambiguous.

Democracy may also affect the pattern of growth of agriculture. Democracy may be associated with better property right definitions, which may increase the incentives for a more sustainable exploitation of privately owned forests. But at the same time, democracy may signal greater benefits to racing for property rights in still unclaimed frontier lands, because people that succeed in this endeavor are likely to get larger benefits in the long run. So the net effect of democracy on agricultural expansion is also ambiguous.

The role of economy-wide policies, Variables (b), especially protectionist trade policies and overvalued exchange rates, as factors that obstruct agricultural growth has been demonstrated in the literature (Krueger, Schiff, & Valdés, 1991). López (2003) has shown that underinvestment in rural public goods, including rural roads and other infrastructure, is another important factor negatively affecting agriculture. In addition, Gardner (2003) has shown that overall, economic growth appears to be a major source of growth for the agricultural sector in many countries. We expect that agricultural expansion increases with more open trade policies and with fiscal policies that lead to a reduction in the risks of overvaluing the exchange rate. In addition, fiscal equilibrium is likely to be associated with a greater provision of public goods by governments, thus having a positive effect on agriculture. We also expect a positive relationship between rural roads and agriculture production. Finally, if Gardner's hypothesis applies, we would expect a significant independent effect of the economy's per capita income on agriculture in forest areas.

Rural road construction is likely to be heavily affected by the ability of the government to finance these investments. This justifies the use of fis-

5. Oftentimes, extending road construction into less populated areas is more closely associated to lobbying, including bribery and political corruption, than to road intensification. Thus, one may expect that greater democracy and participation in civil society may reduce road building in frontier areas as a proportion of total road building.

cal variables as explanatory variables in the road equation. In addition, per capita income is likely to increase the demands for rural roads and increase tax revenues, consequently increasing public funding for road building. We expect a positive relationship between roads and per capita income. Economic openness may increase the demand for roads if trade-oriented production and consumption is more road intensive than domestic production and consumption. Agricultural expansion also increases the demand for rural roads, and governments may respond by supplying more public roads to the rural sector. Hence, we may expect a positive relationship between agriculture and roads. Given these possible links between agricultural production and rural roads, the relationship between these two variables is likely to be simultaneous rather than unidirectional.

THE EFFECTS OF INCOME, GOVERNANCE, AND TRADE POLICY ON FORESTS

The log marginal effects of agriculture area and road building in forest regions on forest area (a_1 and a_2) are obtained from microstudies of deforestation in the Amazon for Brazil and in Thailand for the Asian countries. To derive the overall effect of per capita income on forest cover, we totally differentiate Equation 1, resulting in

$$\frac{dForest}{dGDPPC} = a_1 \frac{dcrop}{dGDPPC} + a_2 \frac{droad}{dGDPPC}. \tag{4}$$

By simultaneously solving for *crop* and *road*, we obtain the following expressions for the effect of per capita income on agriculture area and roads in forest regions:

$$\begin{aligned}\frac{dcrop}{dGDPPC} = \frac{1}{1-\alpha_5\beta_5}[&\alpha_1 + 2\alpha_2 GDPPC + \alpha_6 SATI + \alpha_7 DEM \\ &+ \alpha_5(\beta_1 + 2\beta_2 GDPPC + \beta_6 SATI + \beta_7 DEM)];\end{aligned} \tag{5}$$

$$\begin{aligned}\frac{droad}{dGDPPC} = \frac{1}{1-\alpha_5\beta_5}[&\beta_1 + 2\beta_2 GDPPC + \beta_6 SATI + \beta_7 DEM \\ &+ \beta_5(\alpha_1 + 2\alpha_2 GDPPC + \alpha_6 SATI + \alpha_7 DEM)].\end{aligned} \tag{6}$$

Using Equations 5 and 6 in Equation 4, we obtain the total effect of per capita income on forest cover. The steepness of the forest-income curve and its turning point (the per capita income level at which the slope of the forest-income curve becomes 0), if it exists, are affected by not only the stage of country development but also its trade openness and degree of democracy. In addition to affecting the slope of the forest-income relationship, trade openness and democracy can have independent effects on the level of the forest for given levels of development. These level effects are obtained using the following equations:

$$\frac{dForest}{dGDPPC} = \frac{1}{1-\alpha_5\beta_5}\{a_1[\alpha_3 + \alpha_7 GDPPC + \alpha_5(\beta_3 + \beta_7 GDPPC)] + a_2[\beta_3 + \beta_7 GDPPC + \beta_5(\alpha_3 + \alpha_7 GDPPC)]\}; \tag{7a}$$

$$\frac{dForest}{dSATI} = \frac{1}{1-\alpha_5\beta_5}\{a_1[\alpha_4 + \alpha_6 GDPPC + \alpha_5(\beta_4 + \beta_6 GDPPC)] + a_2[\beta_4 + \beta_6 GDPPC + \beta_5(\alpha_4 + \alpha_6 GDPPC)]\}. \tag{7b}$$

The forest-income relationship may be characterized by a U-shaped relationship or, alternatively, by other functional forms. If the function is U shaped, the turning point can be derived by making the right-hand side of Equation 4 equal 0, after substituting in Equations 5 and 6. Though the turning point is necessarily positive, it is possible that this value is outside the range of the sample per capita income and may be beyond any reasonable level of income altogether. In the latter case, we say that an empirically meaningful Environmental Kuznets Curve does not exist. In addition, the turning point depends on the economy's openness to trade and on democracy. Thus, conditional on the turning point having a meaningful value, one can test whether trade and democracy accelerate or retard the turning point.

DEFORESTATION AND CARBON DIOXIDE EMISSIONS

The volume of carbon dioxide emissions from forest clearing depends on the area of forest being cleared, the area that is allowed to regrow into forest, the total live biomass, and the biomass burning efficiency or the portion of biomass that is released as carbon dioxide when such biomass is burned. The following formula is broadly used in primary tropical forest emission studies (Naughton-Treves, 2004):

$$C_{fc} = (A_{fc} - A_{fr}) \bullet B_f \bullet F_c \bullet E_f \tag{8}$$

where C_{fc} is carbon dioxide flux from clearing mature or primary forest, measured in megagrams (10^6 g); A_{fc} and A_{fr} are the areas of transition from forest to clearance and from forest to forest regrowth in hectares (ha); B_f is aboveground live biomass of mature forest megagrams per hectare (Mg/ha); F_c is the carbon dioxide fraction of dry biomass; and E_f is the burning efficiency of mature forest clearance, which refers to the percentage in heat content in the wood that can be extracted and used. In her analysis of emissions of primary tropical forest in the Peruvian Amazon, Naughton-Treves (2004) used values of 0.5 for F_c, 407 Mg/ha for B_f, and 0.27 for E_f. She assumed no subsequent reburning of the forest. This assumption implies that only a small portion of the biomass that resides in the trunk is released into the atmosphere. The estimated value of E_f increases to 0.4 if reburning of primary forests occurs (Crutzen & Andreae, 1990).

The above formula applies for primary forests. However, parts of the cleared forest are not primary forests but fallow or secondary forests. These are areas where shifting cultivation systems prevail. For measuring carbon dioxide emissions from secondary growth forest clearance, Naughton-Treves (2004) used a slightly different formula:

$$C_{rc} = A_{rc} \bullet B_r \bullet F_c \bullet E_r \tag{9}$$

where C_{rc} is the carbon dioxide flux from secondary forest clearance, A_{rc} is the area of regrowth (secondary forest) to clearance transition (ha), B_r is the average biomass (Mg) for regrowth at the time of clearing, F_c is the carbon dioxide fraction of dry biomass, and E_r is the burning efficiency of secondary forest clearance. The biomass from fallow forest is defined by $B_r = G_r \bullet P$, where G_r is the average accumulation of aboveground biomass during fallow period (P). Based on the field biomass surveys, Naughton-Treves (2004) assume that G_r is 11.5 Mg C/(ha year), E_r is 0.6, and that an average fallow period (P) is 3.2 years.

Our estimates of the carbon dioxide emissions from forests may be subject to two opposing biases caused by the assumptions required to be made as a consequence of insufficient data. First, because of the lack of data on logging, we have implicitly assumed that all forest clearing proceeds through burning. If part of the forest clearing occurs through logging, the amount of carbon dioxide released into the atmosphere is lower. This causes an upward bias of the emission estimates.[6] Second, we lack data on the differential capacities of forest-covered soils to store carbon dioxide vis-à-vis deforested soils. Because the latter are able to retain less carbon dioxide than the former, omitting soil carbon retention causes a downward bias in our estimates.

HYPOTHESES[7]

The following hypotheses are formulated:

6. Logging is an important source of forest clearing in the three Asian countries we study but not in Brazil, where forests are burned for agricultural purposes.

7. All hypotheses tests relate to forest area. However, they also relate to carbon dioxide emissions because, as discussed below, we have modeled the relationship between forest area and carbon dioxide emissions as linear and deterministic.

1. On the Environmental Kuznets Curve. The forest-income relation is nonlinear. Forest area first declines and then increases with per capita income beyond the turning point. This requires that the marginal effect of income on forest be increasing in income and that

$$D \equiv \frac{d(dForest\ /\ dGDPPC)}{dGDPPC} = \frac{2}{1-\alpha_5\beta_5}[a_1(\alpha_2+\alpha_5\beta_2)+a_2(\beta_2+\alpha_2\beta_5)] \geq 0. \qquad (10)$$

   The alternative hypothesis is $D < 0$. Even if this condition is satisfied, however, this does not necessarily mean that a turning point exists within a reasonable income range.

2. On democratization and globalization. Forest area is larger in more democratic and more trade-open countries, ceteris paribus. Testing these hypotheses amounts to testing the null hypothesis that the right-hand side of (7a) and (7b) are both positive. Because these expressions depend not only on parameters but also on the level of per capita income, the test is conditional on a range of per capita income level.
3. On turning points. The level of per capita income at which the forest-income curve changes its slope sign, the turning point, is lower in more democratic and more open countries. To test the hypothesis that trade openness does not retard the turning point, we test the following:

$$\frac{dY}{dSATI} = \left[\frac{-\{a_1[\alpha_6+\alpha_5\beta_6)]+a_2[\beta_6+\beta_5\alpha_6]\}}{2(a_1(\alpha_2+\beta_2\alpha_5)+a_2(\alpha_2\beta_5+\beta_2))}\right] \leq 0; \qquad (11)$$

   where Y is the turning point of Environmental Kuznets Curve derived from equating Equation 4, after substituting Equations 5 and 6, to 0 and solving for *GDPPC*. To verify that democracy does the same, we test the following:

$$\frac{dY}{dDEM} = \left[\frac{-\{a_1[\alpha_7+\alpha_5\beta_7)]+a_2[\beta_7+\beta_5\alpha_7]\}}{2(a_1(\alpha_2+\beta_2\alpha_5)+a_2(\alpha_2\beta_5+\beta_2))}\right] \leq 0. \qquad (12)$$

The Data[8]

Both road networks and agricultural area in forests are region specific. We rank the geographic units in each country from highest to lowest in terms of its total forest cover. The subset of the highest ranked geographic units, which accounts for 80% of the country's total forest cover,

8. An expanded explanation of the derivation of data used in the regressions is available in López, della Maggiora, and Galinato (2002).

is considered a forested region.[9] Regional data are collected from each country's statistical yearbook, giving us a unique panel data set on roads and crop area expansion into the forested regions (as defined above) in the countries considered. Thus, for the case of roads data, we add the total road length in each of the regions we identify as forested to arrive at a country measure of roads in forest regions. Also, total hectares of the forest-encroaching crops planted were aggregated in each country by adding the hectares within the defined forest regions. The main crops grown in the Brazilian Amazon are bananas, coffee, rice, cassava, and soybeans (Chomitz & Thomas, 2003). In Indonesia, rubber, palm oil, and coconut were identified as major crops eroding forestland (Chomitz & Griffiths, 1996). Rubber, palm oil, cocoa, and rice are also major crops produced in Malaysia (Barraclough & Ghimire, 2000). In the Philippines, most farmers in the upland region plant upland rice, corn, and root crops (Lawrence, 1997).

The economy-wide data used consist of annual data for Brazil, Indonesia, Malaysia, and the Philippines for the period from 1970 to 1995. The indicator of trade openness is intended to measure the degree of openness of trade policy rather than trade volumes. We use data developed by López and Galinato (in press) that normalize trade flows following a methodology used by Pritchett (1996).[10] The index can be interpreted as an indicator of a country's trade policy openness with respect to the norm.[11] More open (close) countries will have more positive (negative) index values. The DEM is intended to capture the degree to which a country is considered to be either an institutionalized democracy or autocracy. Because countries usually exhibit mixed qualities of these extreme patterns of authority, Marshall and Jaggers (2002) developed a scale from –10 to 10 that measures the degree to which a country is considered democratic or autocratic. Countries with larger positive (negative) polity values have a more democratic (autocratic) system. The democracy variable aims to measure the degree of civil society participation, government transparency, and quality of institutions.[12] Table 1 summarizes the 5-year average of selected variables for the period from

9. The forested regions of Indonesia are identified as Sumatra, Kalimantan, and Irian Jaya; of Malaysia as Sarawak and Sabah; of the Philippines as Cagayan Valley, Southern Tagalog, Eastern Visayas, Northern Mindanao, and Southern Mindanao; and of Brazil as Acre, Amapa, Amazonas, Maranhao, Mato Grosso, Para, Rondonia, and Roraima.

10. Several studies have estimated trade-openness indicators using various methods (Barro & Lee, 1994; Frankel & Rose, 2002), whereas others have reviewed different trade and openness indicators (Anderson, 1998).

11. See López et al. (2002) for a more in-depth discussion of the derivation and interpretation of this variable.

12. See Marshall and Jaggers (2002) for an in-depth explanation of these data.

Table 1
Summary Statistics for Brazil, Indonesia, Malaysia, and the Philippines

	5-Year Averages					
	1970 to 1974	*1975 to 1979*	*1980 to 1984*	*1985 to 1989*	*1990 to 1994*	*1995 to 1999*
Brazil						
GDP per capita	2,875.04	3,756.95	3,932.98	4,254.73	4,108.78	4,491.67
Crop area (in thousand ha)	4,790.31	2,727.92	2,991.91	3,788.64	4,091.56	4,783.07
Road area (in thousand km)	NA	6,816.00	8,864.00	12,359.00	15,006.40	15,651.50
Trade index	–15.83	–25.23	–21.92	–27.64	–26.51	–28.23
Democracy index	–8.00	–4.00	–3.40	7.40	8.00	8.00
Forest length (in thousand ha)[a]					566,998.00	543,905.00
Indonesia						
GDP per capita	331.96	425.98	544.95	656.69	878.44	1,045.04
Crop area (in thousand ha)	4,396.66	4,884.20	5,649.28	6,703.53	8,106.64	9,624.38
Road area (in thousand km)	NA	15,323.40	22,644.00	36,465.60	55,278.00	67,607.50
Trade index	12.28	21.92	32.28	27.12	14.89	15.03
Democracy index	–7.00	–7.00	–7.00	–7.00	–7.00	–3.80
Forest length (in thousand ha)[a]					118,110.00	104,986.00
Malaysia						
GDP per capita	1,535.19	1,956.32	2,484.54	2,686.35	3,548.99	4,536.23
Crop area (in thousand ha)	515.98	562.34	721.26	984.66	1,161.34	1,500.26
Road area (in thousand km)	669.60	1,310.80	2,676.80	3,717.20	5,311.80	6,923.8
Trade index	13.02	13.88	24.18	34.55	74.84	105.00
Democracy index	3.40	4.00	4.00	4.00	4.00	3.00
Forest length (in thousand ha)[a]					21,661.00	19,292.00

(continued)

Table 1 (continued)

	5-Year Averages					
	1970 to 1974	*1975 to 1979*	*1980 to 1984*	*1985 to 1989*	*1990 to 1994*	*1995 to 1999*
Philippines						
GDP per capita	896.09	1,060.27	1,152.72	1,015.69	1,061.53	1,125.81
Crop area (in thousand ha)	NA	NA	207.47	175.94	148.37	132.71
Road area (in thousand km)	NA	NA	NA	NA	9,496.72	11,503.24
Trade index	–16.32	–24.18	–24.00	–17.37	–6.04	2.63
Democracy index	–4.60	–9.00	–7.20	3.80	8.00	8.00
Forest length (in thousand ha)[a]					6,676.00	5,789.00

Note: ha = hectare; NA = not applicable. GDP per capita is in constant U.S. dollars.

a. Forest area is based on the Food and Agriculture Organization Global Forest Resource Assessment statistics for 1990 and 2000.

1970 to 1999. The appendix shows the data definition and sources of the variables used in the regression.[13]

Results

We estimated the crop and road equations using instrumental variables.[14] The estimates were obtained using a fixed-effect method. The fixed effects are intended to control for country-specific factors, such as land size, initial forest areas, and other factors that do not change with time. Because of the limitation in space, we present only the crop and road regression estimates chosen based on strong explanatory power and the robustness of the coefficients.[15]

DETERMINANTS OF ROAD BUILDING AND CROP EXPANSION

Table 2 summarizes the regressions results for the road and crop equations. Trade openness and governance play a consistently important role in determining agriculture expansion and road building in forest regions. Openness to trade induces the opposite effects on crop production in Brazil and the Philippines on one hand and Indonesia and Malaysia on the other. However, the effect of trade openness in all countries increases road building. By contrast, openness to capital has a negative effect on agriculture area and road expansion. Consistent with earlier analyses, exchange rate overvaluation, represented by the black market exchange rate premium, consistently has a dampening effect on agriculture expansion. Democracy has a significant and positive impact on road building. Thus, the infrastructure expansion appears to dominate the road intensification effect discussed earlier in this article.

The role of per capita income is highly significant in the road equations. Per capita income has potentially nonmonotonic effects on roads that are consistent with an inverted-U–shaped road-income relationship. Similarly, the road-income relationship reflects significant and

13. Supplemental data may be found online at http://jed.sagepub.com/content/vol14/issue1/.

14. The instruments used were the trade-openness index, foreign direct investment as a percentage of GDP, overall budget surplus, black market premium, inflation rate, GDP per capita, and country dummies.

15. A large number of alternative specifications for the two equations were tried with and without annual time dummies for the crop equation and with and without 5-year time dummies to allow for longer run common-to-the-countries effects for the crop and road equations, allowing certain coefficients to vary across countries and allowing for various specifications using different combinations for interactive terms across variables. See López and Galinato (2004) for a complete list of regression results.

Table 2
Regression for the Crop and Road Equations

	Crop Regression		*Road Regression*	
Variable	B	SE	B	SE
Intercept	–0.207	5.293	–57.216***	18.009
Brazil intercept dummy	2.300***	0.393	–4.332***	1.012
Indonesia intercept dummy	3.684***	0.294	–3.604**	1.779
Malaysia intercept dummy	1.820***	0.400	–5.225***	0.798
Trade openness index	–0.022***	0.003	0.039*	0.023
Trade openness slope dummy for Indonesia and Malaysia	0.025***	0.004	–0.020***	0.010
Foreign direct investment	–0.050	0.034	–0.038***	0.018
Log inflation rate			–0.004	0.023
Black market premium rate	–0.222***	0.109		
Log GDP per capita	0.417	1.499	16.594***	5.133
Log GDP per capita squared	–0.005	0.112	–1.017***	0.344
Log GDP per capita × Trade Openness Index			–0.002	0.003
Predicted value of crop production			1.027***	0.242
Predicted paved forest roads	0.267***	0.124		
Democracy index	0.002	0.003	–1.665***	0.798
Log GDP per capita × Democracy Index			0.205***	0.096
Log likelihood	70.89		50.72	
Number of observations	57		47	

Note: All standard errors are heteroskedastic-consistent. *15% level of significance. **10% level of significance. ***5% level of significance.

robust positive interaction with democracy but not with trade policy. Thus, democracy appears to exacerbate the positive effect of income.

INTEGRATING THE NEW ESTIMATES WITH MICROESTIMATES

To measure the effects of per capita income, democracy, and trade policy on forest cover, we integrate the estimates of the crop and road equations with estimates from existing microstudies. Among existing microstudies that have measured the effect of road networks and crop production on forest cover in a particular country, we consider those that have used local surveys to obtain socioeconomic data and that have used remote sensing data to measure actual deforestation at the local level. We have chosen among this limited set the studies that seem the most suited for our purposes based on location and methodology. We use the marginal effects estimated from the microstudies and recalculate the relevant elasticities using the respective country-specific endowments of forest cover and direct factors in each of the four countries. This procedure mitigates the potential inconsistencies that may arise as a result of adopting estimates from microstudies obtained from countries other than the four focus countries.

To obtain direct estimates on the effect of roads on forest cover, estimates from two studies are used. For Brazil, we use the estimates by Pfaff (1999) for the Amazon region. For the three Asian countries, we use the estimates by Panayotou and Sungsuwan (1994) for Thailand. Pfaff arrives at a marginal effect of paved roads on percentage of forest area of –2.1 for Brazil. Using the statistics from his study, we arrive at an elasticity of paved roads on forest area change on the order of –0.007. Panayotou and Sungsuwan obtain an elasticity of forest to paved roads of –0.11 in Thailand. We use the marginal effects of roads on forests implicit in the Panayotou and Sungsuwan study and use them for the three Asian countries.

Chomitz and Thomas (2003) estimated the effect of crops encroaching on forested land in the Brazilian Amazon. We assume that the marginal effect of one additional hectare of crops in forest areas leads to the same area of forest clearing in Brazil as in Asia. However, because of differences in the crop area and forest ratios among the countries, the resulting elasticities are quite different. On the basis of Chomitz and Thomas's estimates, we calculate the implicit marginal effect to be about 4.7. That is, one additional permanent hectare of cultivation requires clearing of 4.7 hectares of forests. This number is greater than 1 because a permanent increase of land cultivated requires additional land for associated human settlement, more infrastructure, land rotation (cycles of 3 to 5 years of fallow and cultivation are not uncommon in the context of shifting cultivation systems), and other associated activities. The marginal cultivation effect of forest clearing is quite stable across different countries. López (1997, 2000), for example, found that this value was about 3.9 in Ghana and 4.4 in western Cote d'Ivoire. These numbers are remarkably similar to the implicit values obtained by Chomitz and Thomas in Brazil.

Per capita income and forest cover. Table 3 provides a summary of the estimates that integrates our estimates of the crop and road equations with the microestimates, including their respective standard errors. The income elasticities as well as the effects of trade policy and democracy are evaluated at the mean levels of the relevant variables. The elasticities of per capita income are provided in the first block of Table 3 using Equation 5 for crop, Equation 6 for road, and Equations 4 to 6 for forest cover. Income elasticities on forest cover are negative and significant at a 5% level of significance in the three Asian countries. For Brazil, this elastic-

Table 3
Percentage Changes in Crop Production, Road Building, and Forest Cover Resulting From a Unit Change in the Trade Index and Democracy Index and a Percentage Change in GDP Per Capita

	Elasticity of GDP Per Capita						*Unit Change in Trade Index*						*Unit Change in Democracy Index*					
	Crop Production		*Road Building*		*Forest*		*Crop Production*		*Road Building*		*Forest*		*Crop Production*		*Road Building*		*Forest*	
Country	B	SE	B	SE	B	SE	B	SE	B	SE	B	SE	B	SE	B	SE	B	SE
Brazil	0.694	0.521	1.332	0.833	–0.042	0.033	–2.151**	0.005	0.152**	0.012	0.098**	0.0005	1.854**	0.282	6.123**	0.017	–0.131**	0.013
Indonesia	1.139**	0.235	2.939**	0.429	–0.835**	0.333	0.616**	0.006	1.298**	0.008	–0.420**	0.004	–11.352**	0.310	–43.428**	0.232	9.881**	0.159
Malaysia	0.946**	0.306	2.264**	0.536	–0.674**	0.301	0.525**	0.005	0.953**	0.006	–0.341**	0.003	–1.381**	0.288	–6.016**	0.057	1.283**	0.131
Philippines	1.555**	0.435	4.514**	0.819	–1.195**	0.511	–2.059**	0.005	0.499**	0.013	0.871**	0.005	–8.205**	0.303	–31.618**	0.177	7.166**	0.149

Note: Estimates are calculated using mean values of GDP per capita, trade index, and democracy index for each country. The values of d_1 and d_2 for Brazil are –0.046 and –0.007, respectively. For the other Southeast Asian countries, d_1 and d_2 are –0.450 and –0.110, respectively.
*$p < .10$. **$p < .05$. Chi-square critical values at 5% and 10% are 3.84 and 2.71, respectively.

ity is also negative but not significant. For the three Asian countries, the forest-income elasticity is negative and significant when evaluated at all income levels within the observed values for the period. For Brazil, the elasticity is also significant when evaluated at income levels prevailing earlier in the period, but when evaluated at the more recent observed (higher) per capita income levels, the effect becomes less significant. This would suggest that Brazil, unlike the Asian countries, may not be too far from the turning point.

For the three Asian countries, the income elasticities on forest cover are not only significant and negative but also quite sizable, ranging from –0.67 to –1.2. In these countries, economic growth is likely to be responsible for a large rate of deforestation. The positive effects of per capita income on both agriculture expansion and road building are behind the high impact of income growth on deforestation, with the road-building channel having a more significant effect.

Trade openness and forest cover. The impact of trade openness on forest cover is significant in all countries but in the opposite direction for Brazil and the Philippines, where it is positive, vis-à-vis Indonesia and Malaysia, where trade causes a reduction of forest cover. The main factor explaining these differences among the countries is the differential effect of trade on agriculture expansion, which is negative in Brazil and the Philippines but positive in the other two countries. This is most likely related to the patterns of trade of forest-competing agriculture in the countries. In Indonesia and Malaysia, forest-competing agriculture is clearly export driven, whereas in Brazil, it is more directed toward a mix of import substitution and, only recently, some export-oriented crops, such as soybeans. In the Philippines, forest-competing agriculture is clearly oriented to the domestic market. Thus, in the latter two countries, unlike in Indonesia and Malaysia, the net effect of openness decreases incentives to forest-competing agriculture.

The effect of trade openness on forest is not only significant, but its quantitative impact appears to be quite large. Consider the case of Brazil, which has had a fairly high and more or less constant degree of trade protection since 1985. For example, if Brazil had permanently increased its degree of trade openness in 1985 to levels 50% equivalent to those prevailing in Malaysia from 1985 to 1990, total forest cover in Brazil would be estimated to increase by almost 4%. This is of course a once-and-for-all effect that may take several years to be reached. If we assume that the forest adjustment to the new trade policy takes 15 years, forest cover would have been 23 million hectares bigger in the year 2000 than what it actually was in the same year, ceteris paribus. Because deforestation in Brazil in the 1990s is estimated at 2.4 million hectares per annum, this means that the more open trade policy would predict an annual deforestation of only about 1 million hectares per year. Annual carbon dioxide emissions resulting from deforestation would be predicted to fall by 50 to 77 million metric tons.

Similar calculations for Indonesia yield opposite results. If in 1985 Indonesia had increased trade openness to the level prevailing in Malaysia at the time, there would have been 3 million hectares less of forest in 2000. Annual deforestation from 1985 to 2000 would have increased from 1.2 million to 1.4 million hectares, and forest-induced carbon dioxide emissions would have increased in the range of 11 to 16 million metric tons per year.

Democracy and forest cover. Democracy has a positive and significant effect on forest cover in all countries except in Brazil, where its effect is opposite in sign. The magnitude of the effects, especially in Indonesia and the Philippines, may seem inordinately large. However, it is important to realize that in these latter two countries, the DEM is extremely low (even negative in some cases), so the implicit proportional effect is not unreasonable. For example, in the Philippines, the average DEM is about 2.0 for the period under analysis. This means that a unit increase of the DEM is equivalent to a very large percentage increase in democracy, about 50%. So the implicit elasticity is only 0.14 (7.0/50). An important finding is that the impact of more democracy on deforestation is estimated to be greater at lower per capita income levels. At sufficiently high-income levels, the effect of democracy may even change the direction of its effect on forests.

We used other measures of governance and found little difference in the results. In particular, some of the Institutional Reform and the Informal Sector (IRIS) indices, which include corruption in government, rule of law (law and order tradition), bureaucratic quality, ethnic tensions, repudiation of government contracts, and expropriation risk, were considered.[16] The results were consistent to the interpretation in sign of the democracy variable used in the regression.[17]

TURNING POINTS FOR THE FOREST-INCOME CURVE AND HYPOTHESES TESTS

We calculated the levels of per capita income at which the effect of income on forest changes from negative to positive, as predicted from the estimated model.[18] For Brazil, Malaysia, and the Philippines, the turning points are predicted to be around $7,000 to $8,000, compared to

16. IRIS data are derived from IRIS (1995).

17. See the newly revised version of López and Galinato (2004) for regression results with IRIS data.

18. Because of limitation in space, we have chosen not to include a table for the turning points statistics. Simulated values can be seen in López and Galinato (2004).

Table 4
Summary of the Hypotheses Tests

Country	*Effect of Income on the Marginal Effect of Income on Forest*[a]		*Effect of Trade Openness on Turning Points*[b]		*Effect of Governance on Turning Points*[c]	
	B	SE	B	SE	B	SE
Brazil	.0557**	.0235	–.0009	.0015	.0997**	.0369
Indonesia, Malaysia, and the Philippines	.6507*	.3322	–.0009	.0015	.0998**	.0345

a. Hypothesis 1, testing $D \geq 0$ as defined by Equation 10.
b. First part of Hypothesis 3 testing inequality, Equation 11.
c. Second part of Hypothesis 3 testing inequality, Equation 12.
$^*p < .10$. $^{**}p < .05$. Chi-square critical values at 5% and 10% are 3.84 and 2.71, respectively.

current per capita incomes of about $4,500 for Brazil and Malaysia and $1,200 for the Philippines. For Indonesia, the turning point is much lower at about $2,600 but still well above the $1,050 corresponding to the current per capita income of this country. The turning point varies by country but is still well beyond the current per capita income levels in all countries. The fact that the predicted turning points are beyond the observed per capita income levels within the data sample significantly increases the uncertainty regarding the true level of such points and even their very existence. Thus, relying on growth as a cure to deforestation is risky for these countries; at best, it may take a long time to reach the turning points. At worst, forest-benign growth may not happen before the tropical forests are mostly eliminated.

Table 4 summarizes the results from the three hypotheses tests. For all four countries, we find that Hypothesis 1 is confirmed: Per capita income reduces forests, but the marginal effect of income becomes less negative as income continues to grow and may eventually become positive at sufficiently high-income levels. This implies that an environmental Kuznets U-shaped relationship between forest and income cannot be ruled out. The necessary (but not sufficient) conditions for the existence of an Environmental Kuznets Curve are statistically verified.

Hypothesis 3 regarding trade (Equation 11), which states that trade openness reduces the income level at which the turning point occurs, is rejected. Trade policy does not have any statistically significant effect on the turning point. Hypothesis 3 regarding democracy (Equation 12), which states that democracy advances the turning point of the forest-income curve, is rejected. Moreover, the alternative hypothesis, which states that democracy delays the turning point, cannot be rejected.

Hypothesis 2 concerning the effect of democracy is accepted for the Asian countries but is rejected for Brazil. We found that the forest-

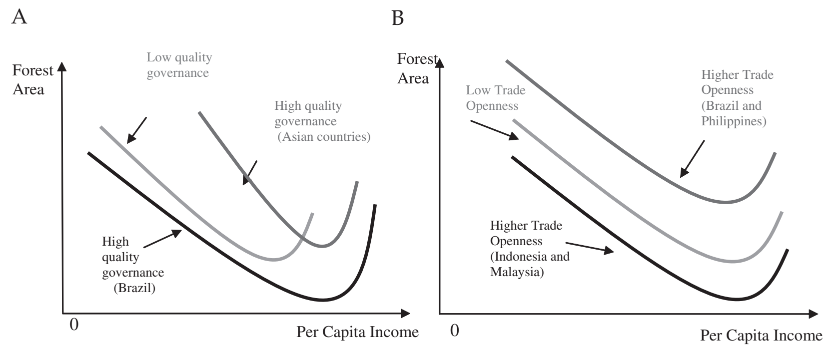

Figure 2: Government Policies and the Forest-Income Curve: Governance and the EKC (A), and Trade Policy and the EKC (B)

Note: EKC = Environmental Kuznets Curve.

income curve shifts upward when governance improves for the Asian countries, whereas it shifts downward for Brazil when there is an increase in the quality of governance (Figure 2A). Hypothesis 2 concerning trade is rejected for Malaysia and Indonesia but is accepted for Brazil and the Philippines (Figure 2B). Because trade policy does not affect the turning point in any of the four countries, in Figure 2B, we represent increased trade openness by parallel shifts of the forest-income curve. For Indonesia and Malaysia, the curve shifts downward, whereas for Brazil and the Philippines, the curve shifts upward.

CARBON DIOXIDE EMISSIONS FROM FOREST CLEARING

Table 5 shows the importance of carbon dioxide emissions caused by deforestation in the late 1990s, comparing them with industrial emissions. As can be seen, forest clearing explains a significant share of total carbon dioxide emissions in the countries under consideration. Depending on the assumptions regarding burning efficiency, deforestation contributes between 27% and 35% of total emissions in Brazil and between 20% and 26% in Indonesia. For the other two countries, the contribution of deforestation to carbon dioxide release is less but still far from negligible.

We also use the estimated equations to simulate the contribution of economic growth to deforestation along with the associated carbon dioxide release into the atmosphere from 1991 to 2001. Observed economic growth in Brazil explains less than 15% of the total estimated levels of deforestation (i.e., 270,000 hectares per annum out of 2.3 million hectares). Also, economic growth explains 3% to 4% of the total emissions of carbon dioxide resulting from deforestation (i.e., approximately 15 million metric tons per year out of 126 million metric tons in the lower bound case). In the Philippines, income growth explains a much greater

Table 5
Estimated Annual Carbon Dioxide Emissions and Carbon Dioxide Release Explained by the Growth in GDP Per Capita From 1991 to 2001

	Brazil	*Indonesia*	*Malaysia*	*Philippines*
Estimated Annual Carbon Dioxide Emissions				
Annual Carbon Dioxide Emissions From the Industrial Sector[a] (in 1,000 Mg)	338,003	274,832	111,641	70,159
Lower Bound Annual Carbon Dioxide Release From Forest Clearing[b] (in 1,000 Mg)	125,888	66,816	12,102	4,797
Percentage of Carbon Dioxide Emissions Resulting From Forest Cover Change From Total Carbon Dioxide Emissions	27.14	19.56	9.78	6.4
Lower Bound Annual Total Carbon Dioxide Emissions (in 1,000 Mg)[c]	463,891	341,649	123,744	74,956
Upper Bound Annual Carbon Dioxide Release From Forest Clearing[d] (in 1,000 Mg)	186,380	98,346	17,819	7,097
Percentage of Carbon Dioxide Emissions Resulting From Forest Cover Change From Total Carbon Dioxide Emissions	35.54	26.35	13.76	9.19
Upper Bound Annual Total Carbon Dioxide Emissions (in 1,000 Mg)[e]	524,383	373,179	129,461	77,257
Carbon Dioxide Emissions Resulting From Economic Growth				
Average Annual Growth of GDP Per Capita, 1991 to 2001	1.2	2.6	4.2	0.65
Average Annual Change in Forest Cover Resulting From Economic Growth (ha)	–273,184	–2,279,674	–546,452	–44,985
Lower Bound Annual Carbon Dioxide Release From Forest Clearing Resulting From Economic Growth[b] (in 1,000 Mg)	14,892	116,062	27,916	2,433
Percentage of Carbon Dioxide Emissions Resulting From Forest Cover Change From Total Carbon Dioxide Emissions	3.21	33.97	22.56	3.25
Upper Bound Annual Carbon Dioxide Release From Forest Clearing Resulting From Economic Growth[d] (in 1,000 Mg)	22,048	170,830	41,102	3,599
Percentage of Carbon Dioxide Emissions Resulting From Forest Cover Change From Total Carbon Dioxide Emissions	4.2	45.78	31.75	4.66

a. Carbon dioxide emissions from fuel consumption in 2000 is used. Data are from the Energy Information Administration (2004).
b. Annual carbon dioxide release is calculated using an efficiency burning (E_i) of .27 for mature forest clearing.
c. This is calculated by adding Rows 1 and 2.
d. Annual carbon dioxide release is calculated using an efficiency burning (E_j) of .6 for mature forest clearing.
e. This is calculated by adding Rows 1 and 5.

share of the observed deforestation, approximately 50%, which is 45,000 hectares out of a total annual deforestation of 88,000 hectares and between 3% and 4.7 % of the total emissions from all sources. In Indonesia and Malaysia, economic growth explains deforestation and deforestation-induced emissions by 98% and more than 100%, respectively. Furthermore, between 33% to 45% and 22% to 31% of all emissions are explained by deforestation-induced emissions resulting from income growth in Indonesia and Malaysia, respectively. This means that the net effect of nongrowth factors has been to dramatically exacerbate the deforestation and carbon dioxide emission effects of income growth in Brazil and the Philippines. By contrast, in Malaysia and Indonesia, nongrowth factors may have partly mitigated the negative environmental effects of economic growth.

Deforestation-induced carbon dioxide emissions are connected to per capita income in a fundamentally different way than industrial emissions are. Although industrial emissions occur even if per capita income and other relevant exogenous variables do not change, deforestation emissions are positive only if income or some other exogenous variables are changing, thus causing forest clearing. This implies two things:

1. The environmental Kuznets forest emissions-income curve has to be interpreted differently from the corresponding curve for industrial emissions. For any level of per capita income, the levels of carbon dioxide emission are really undefined because they will depend on the rate of change of the income at that point and not on the level of income. So if one superimposes the forest-income curve with a carbon emissions line, the position of the carbon line is not defined unless we assume a certain rate of growth of income. Figure 3 illustrates carbon dioxide emissions for Brazil during the 1990s. We have drawn the emissions line assuming that the rate of per capita income growth is constant and equal to the observed average annual rate of growth in Brazil during the 1990s.
2. Forest-related emissions are equal to 0 at the turning point of the forest-income curve and become negative beyond such a level of income. This means that the forests in such countries are in a process of growth and expansion, thus contributing to carbon sequestration from the atmosphere rather than releasing it. If we assume a faster rate of growth of per capita income, the carbon release line in the figures would be steeper, but it would bypass the horizontal axis at the same point at which the forest-income curve turns.

Conclusion

The following conclusions have emerged from this analysis:

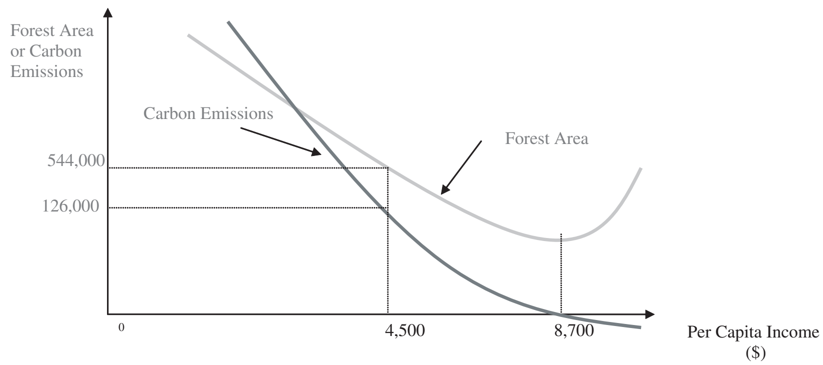

Figure 3: Brazil Forest Area and Carbon Emissions
Note: Per capita income is depicted in thousand 1995 U.S. dollars. Forest area is depicted in hectares (in thousands). Carbon emissions are depicted in metric tons (in thousands).

1. The forest-income relationship in the four countries considered in this analysis is predicted to have an Environmental Kuznets Curve (i.e., a U-shaped curve). However, the turning points of the forest-income curve are predicted to be at income levels well above their current per capita income levels, especially in the Asian countries. Thus, relying on growth as a cure to deforestation is risky.
2. The forest-income relationship is not stable. Its position and shape is heavily influenced by democracy and the quality of governance. Moreover, the way in which the forest-income curve is affected by democracy and trade changes is country specific. Improving democracy and governance shifts the forest-income curve upward in the three Asian countries, but in Brazil, it has the opposite effect. Improving democracy delays the turning point in all four countries. The evidence suggests that the effect of governance on forest is affected by the level of per capita income at which the change in governance takes place. At low-income levels, improving the quality of governance and democracy tends to increase forest cover in the long run, but at high-income levels, the opposite happens.
3. Trade policy shifts the position of the forest-income curve, but it does not affect its predicted turning point. The direction of this shift is also country specific, but unlike the effect of democracy, its effect does not depend on the level of income of the country. It instead depends on the initial level of openness of the country and whether it has comparative advantages in forest-competing crops. Increasing trade openness promotes deforestation in countries that already have a more open-trade regime, producing export-oriented agricultural crops that encroach the forest regions (Malaysia and Indonesia), and it helps reduce deforestation in countries such as Brazil and the Philippines, which have closer trade regimes. Policies may be needed to lessen the impact of trade on forest cover in countries that have export-oriented agricultural products. Policies such as the

removal of subsidies in the production of forest-encroaching crops may be needed to lessen the negative impact of trade on forests.

4. Deforestation-induced carbon dioxide emissions along the downward phase of the forest-income curve are dependent on the rate of per capita income growth. Faster income growth induces a more rapid rate of forest clearing, through road building and increased agricultural land use, and consequently more carbon dioxide emissions. The actual rates of economic growth during the 1990s are estimated to have induced annual deforestation-related carbon dioxide releases equivalent to between 20% and 45% of all forest and industrial emissions in Malaysia and Indonesia. The impact of economic growth on emissions is much lower in Brazil and the Philippines, where factors other than growth are responsible for deforestation and carbon dioxide releases.
5. Improving governance in the Asian countries appears to have had a dramatic effect in partially mitigating the impact of economic growth on deforestation-related carbon dioxide releases, especially in Indonesia and Malaysia. Though the effect of governance on forest cover is very large, this effect is also likely to be dispersed throughout a large number of years.

References

Anderson, J. (1998). Trade restrictiveness benchmarks. *The Economic Journal*, *108*, 111-125.

Barbier, E. B., & Burgess, J. C. (2001). The economics of tropical deforestation. *Journal of Economic Surveys*, *15*(3), 413-433.

Barraclough, S., & Ghimire, K. (2000). *Agricultural expansion and tropical deforestation*. London: Earthscan.

Barro, R. J., & Lee, J. W. (1994). *Data set for a panel of 138 countries*. Retrieved March 13, 2002, from http://www.nuff.ox.ac.uk/Economics/Growth/datasets.htm

Chomitz, K., & Griffiths, C. (1996). *Deforestation, shifting cultivation, and tree crops in Indonesia: Nationwide patterns of smallholder agriculture at the forest frontier*. Retrieved February 10, 2002, from http://www.worldbank.org/research/peg/wps04/tree596.pdf

Chomitz, K., & Thomas, T. (2003). Determinants of land use in Amazonia: A fine-scale spatial analysis. *American Journal of Agricultural Economics*, *85*(4), 1016-1028.

Copeland, B., & Gulati, S. (in press). Trade and the environment in developing countries. In R. López, J. Stiglitz, & M. Toman (Eds.), *Sustainable development: New options and policies*. New York: Oxford University Press.

Copeland, B. R., & Taylor, M. S. (2004). Trade, growth, and the environment. *Journal of Economic Literature*, *42*(1), 7-71.

Cropper, M., & Griffiths, C. (1994). The interaction of population growth and environmental quality. *American Economic Review*, *84*(2), 250-254.

Cropper, M., Puri, J., & Griffiths, C. (2001). Predicting the location of deforestation: The role of roads and protected areas in north Thailand. *Land Economics*, *77*(2), 172-186.

Crutzen, P. J., & Andreae, M. O. (1990). Biomass burning in the tropics: Impact on atmospheric chemistry and biogeochemical cycles. *Science*, *250*(4988), 1669-1678.

Deacon, R. (2000). *The political economy of environment-development relationships: A preliminary framework* (FEEM Working Paper 00/03). Milan, Italy: Fondazione Eni Enrico Mattei.

Deacon, R. (2003). *Dictatorship, democracy, and the provision of public goods* (Economics Working Paper Series 1172). Santa Barbara: Department of Economics, University of California, Santa Barbara.

Energy Information Administration. (2004). *International Energy Annual 2002*. Retrieved July 19, 2004, from http://www.eia.doe.gov/iea/carbon.html

Ferreira, S. (2004). Deforestation, property rights and international trade. *Land Economics*, *80*(2), 174-193.

Frankel, J., & Rose, A. (2002). Is trade good or bad for the environment? Sorting out the causality (NBER Working Paper No. 9201). Cambridge, MA: National Bureau of Economic Research.

Gardner, B. (2003). *Causes of rural economic development*. Plenary session paper presented at Meetings of the International Agricultural Economics Association, Durban, South Africa.

Institutional Reform and the Informal Sector. (1995). *IRIS time series of international country risk guide data, 1982-95.* Retrieved June 24, 2004, from http://www.iris.umd.edu/

Krueger, A., Schiff, M., & Valdés, A. (Eds.). (1991). *Political economy of agricultural pricing policy*. Baltimore: Johns Hopkins University Press.

Lawrence, A. (1997). Kaingin in the Philippines: Is it the end of the forest? *Rural Development Forestry Network*. Retrieved June 20, 2002, from http://www.odifpeg.org.uk/publications/rdfn/21/rdfn-21f-i.pdf

López, R. (1997). Environmental externalities in traditional agriculture and the impact of trade liberalization: The case of Ghana. *Journal of Development Economics*, *53*(1), 17-39.

López, R. (2000). Trade reform and environmental externalities in general equilibrium: Analysis for an archetype poor tropical country. *Environment and Development Economics*, *5*(4), 377-404.

López, R. (2003). *Agricultural development and the environment: Non-market interactions and political economy*. Plenary session paper presented at Meetings of the International Agricultural Economics Association, Durban, South Africa.

López, R., della Maggiora, C., & Galinato, G. I. (2002). *Trade and other economy-wide policies and the direct causes of deforestation* (World Bank discussion paper). Retrieved July 17, 2004, from http://www.arec.umd.edu/rlopez/GovDev/govdev.htm

López, R., & Galinato, G. I. (2004). *Deforestation-induced carbon dioxide emissions in tropical countries: How do governance and trade openness affect the emissions-income relationship?* (EPA discussion paper). Retrieved August 30, 2004, from http://www.arec.umd.edu/rlopez/GovDev/govdev.htm

López, R., & Galinato, G. I. (in press). Trade policies, economic growth and the direct causes of deforestation. *Land Economics*.

Marshall, M., & Jaggers, K. (2002). *Polity IV project, Integrated Network for Societal Conflict Research (INSCR) program, Center for International Development and Conflict Management (CIDCM), University of Maryland, College Park*. Retrieved June 17, 2004, from www.cidcm.umd.edu/inscr/polity

Naughton-Treves, L. (2004). Deforestation and carbon emissions at tropical frontiers: A case study from the Peruvian Amazon. *World Development*, *32*(1), 173-190.

Panayotou, T., & Sungsuwan, S. (1994). An econometric analysis of the causes of tropical deforestation: The case of Northeast Thailand. In K. Brown & D. Pearce (Eds.), *The causes of tropical deforestation* (pp. 192-210). London: University College London Press.

Pfaff, A. (1999). What drives deforestation in the Brazilian Amazon? *Journal of Environmental Economics and Management*, *37*, 26-43.

Pritchett, L. (1996). Measuring outward orientation in LDCs: Can it be done? *Journal of Development Economics*, *49*, 307-335.

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