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Abstract

This article formulates a structural empirical model that measures the short run and long run effect of economic growth, political stability and corruption control on carbon dioxide (CO_2) emissions from deforestation. Income has a negative effect on forest cover in the short run but it does not have any long run effect. In contrast, political stability and corruption have relatively smaller effects on forest cover in the short run but they have lingering long run effects. We derive a U-shaped forest-income curve where political stability and corruption control do not significantly affect the income turning point but both variables shift the curve up or down. The resulting CO_2 emission-income curve is downward sloping and is based on *changes* in the levels of variables affecting forest cover. Increased political stability flattens the CO_2 emissions-income curve leading to smaller changes of CO_2 emissions per unit change in income.

JEL classification: O10, Q23

Keywords: Corruption, Deforestation, Environmental Kuznets Curve, Political stability

Introduction

In developing countries, the dominant contributor to greenhouse gas emissions is land conversion, in particular the conversion of forestland to agricultural, pasture or urban land use. Forests in developing countries, especially those that have significant tracts of tropical forest, retain large volumes of carbon dioxide (CO_2), ranging from 100 to 250 metric tons per hectare (Crutzen and Andreae, 1990; Naughton-Treves, 2004). Land clearing, through slash-and-burn farming or shifting cultivation, leads to a release of stored CO_2 into the atmosphere.

Studying the role of governance on economic growth and sustainable development has become a central focus in the literature (World Bank, 2002). Weak institutions due to corruption or political instability can hinder sustainable development. Corruption skews policies in favor of rent seeking firms (Bulte and Damania, 2008) and reduces public expenditure while political instability creates uncertainty that leads to less resource conservation (Deacon and Mueller, 2004) and a reduction in resource stocks. Given the extent to which the rural economy is dependent on agriculture and forestland, the type of governance could have a significant effect on deforestation-induced CO_2 emissions.

This article measures short run and long run effect of economic growth, political stability and corruption control on CO_2 emissions from deforestation. We present a conceptual model that links how political stability and corruption control influence economic growth which, in turn, affects the direct factors of deforestation leading to releases or sequestration of CO_2. We estimate a structural model to test how political stability and corruption control affect the Environmental Kuznets Curve (EKC) for deforestation-induced CO_2 emissions. Our empirical analysis has important policy implications because it measures the immediate and long term effects of corruption control and political stability on CO_2 emissions in developing countries.

Unlike developing countries, the main source of CO_2 emissions in developed countries is the industrial sector. Empirical findings to test for the existence of an EKC for CO_2 in the national level show mixed results. Various regression results have shown a monotonic (Shafik, 1994), inverted U-shaped (Holtz-Eakin and Selden, 1995; Hill and Magnani, 2002) and N-shaped (Sengupta, 1996) relationship between income and CO_2 emissions.

The mechanisms relating income to industrial CO_2 emissions differ from the mechanisms relating income to deforestation-induced CO_2 emissions. Deforestation depends on direct factors that immediately contribute to the conversion of forestland to other land uses, such as agricultural land expansion and road building, and underlying factors that influence the severity of the direct factors such as economic growth, political institutions and trade openness. The resulting CO_2 emissions-income curve due to changes in forest cover may take a different form.

Reduced-form estimation between per capita income and deforestation using cross-country forest data from the Food and Agriculture Organization (FAO) have found the existence of an EKC relationship between income and forest cover with income turning points not too far from the current levels of per capita income of middle-income developing countries (Barbier and Burgess, 2001; Cropper and Griffiths, 1994). These studies have the advantage of deriving the net effect of income on forest cover but there are two important limitations. First, a reduced form estimation fails to control for the effect of omitted underlying factors. To the extent that these underlying factors are correlated with income, estimates of the effect of income on forest may be biased. Second, FAO forest data are derived through interpolations using a few years of actual data which may also bias the effect of income if income is used as a variable for interpolation.

Microstudies use satellite imaging and GIS data to measure the effect of the direct factors on forest cover. An advantage of these types of studies is the strong quality of forest cover data and direct factors data but it is difficult to analyze the effect of underlying factors on forest cover given the nature of the data. López and Galinato (2005a) overcome this problem by constructing a structural model that estimates the effect of underlying factors on the direct factors of deforestation, and combining them with estimates from microstudies. However, they did not consider the effects of political stability and corruption control.

We define political stability as the ability of the government to implement its programs and stay in office. The quality of infrastructure is positively correlated with political stability of an economy (Gimenez and Sanau, 2007) and affects the creation and enforcement of laws. Thus, countries that are more politically stable are more likely to provide more enforcement of forest protection laws leading to a higher cost for land clearing and less conversion of forest land to agricultural land.

Corruption control affects policy choice as well as availability of funds. Corruption increases the cost of infrastructure building (Kenny, 2006) which affects road building in the rural economy and can affect the set of technologies available for the farmer in the agricultural sector. Bridgman et al. (2007) and Bulte et al. (2007) show how lobbying groups have an incentive to block the adoption of superior technology in order to maximize rents thereby yielding inefficient modes of agricultural production. Thus, an increase in corruption control may increase available technology in the agricultural sector. Depending on the complementarity or substitutability of land and technology, corruption could lead to agricultural intensification or extensification which has a direct effect on forest cover.

There are two studies to our knowledge that tried to integrate different measures of governance to understand the impact of income on forest cover. Lopez and Galinato (2005a) utilize a measure of polity which measures if a country is more democratic or dictatorial. They find that a more democratic country will have a higher turning point than a less democratic country, but the forest-income curve may or may not shift depending on country characteristics. Bhattarai and Hammig (2004) use a reduced form specification to measure the effect of an overall index of governance capturing rule of law, bureaucratic quality and governmental corruption on deforestation rates. They find that improved governance fosters better management of forests resulting in a lower income turning point.

Our study differs from the previos studies because we account for the effect of two different governance variables, political stability and corruption control, in a structural model instead of a reduced form formulation. Furthermore, we extend the empirical methodology of López and Galinato in two ways. First, we increase the number of countries in our sample by creating a unique dataset that isolates the amount of agricultural land encroaching on forestland. Second, we measure the short-run and long-run effect of income and governance on forestland and CO_2 emissions. This is the first study we are aware of that compares the immediate and long term effects of governance and income on deforestation-related CO_2 emissions.

The rest of the article is organized as follows: Section 1 presents the conceptual model. Section 2 formulates the empirical model. Section 3 describes the data. Section 4 presents the results of the regressions and simulations of CO_2 emissions from deforestation. Section 5 concludes the study.

1. Conceptual model

Figure 1 depicts the conceptual foundation linking governance variables and economic growth to deforestation-induced CO_2 emissions. We outline three blocks of causation and use different approaches to integrate each aspect into our empirical estimation.

In Block I, we use a new dataset to empirically estimate the effect of economic growth and governance on the direct factors of deforestation. The direct factors of deforestation immediately contribute to the conversion of forest land to other land uses. We focus on two key direct factors: agricultural land expansion and road building. There may be a bi-causal relationship between agricultural land clearing and road building because road construction into forest regions induces land clearing for agricultural purposes and agricultural expansion leads to increased lobbying to develop rural infrastructure.[1] The decision to expand land for agricultural purposes or the decision to build roads is dependent on underlying factors such as economic growth (Koop and Tole, 1999), political institutions (Nguyen Van and Azomahou, 2007) and trade openness (López and Galinato, 2005b).

Galinato and Galinato (2010) develop a theoretical model relating two measures of governance, political stability and corruption control, on the choice of farmers to expand agricultural land and the choice of the local government to build rural infrastructure. They show that increased corruption control could lead to agricultural extensification (intensification) and less (more) rural road building when land and technology are complements (substitutes) and when the effect of corruption control on the cost of infrastructure is low (high). Political stability also has an ambiguous effect on agricultural land clearing and rural road building because more political stability only assures policy continuation. If environmental policies are stringent, more political stability implies higher cost of land clearing but the opposite holds if environmental policies are lax.

Economic growth directly increases agricultural land expansion but has an ambiguous effect on rural road infrastructure. For example, unpaved roads may decrease as the economy

[1] Logging has its own dynamics partly independent of road construction. However, initial logging is usually followed by agricultural expansion making it difficult to separate the effect of logging from agricultural expansion.

grows because they are considered inferior goods while paved road construction may increase because they are normal goods.

In Block II, we use existing studies in the literature that estimate the effect of agricultural land expansion and road building on forest cover. A number of recent microstudies that analyze the determinants of deforestation relied on data from satellite images, local surveys and remote sensing (Panayotou and Sungsuwan, 1994; Chomitz and Thomas, 2003; Cropper et al., 2001; López, 1997 and 2000). There is a consistent negative effect of expansion of agricultural land and road building on forest cover.

In Block III, we simulate the effect of a change in forest cover on CO_2 emissions. Any reduction in forest cover leads to a release of CO_2. We combine our estimates from Blocks I and II with the simulated estimates in Block III to arrive at the total effect of underlying factors such as economic growth and governance on deforestation-induced CO_2 emissions.

2. Empirical model

Using our conceptual framework, we start by postulating the impact of the direct factors on forest cover from Block II,

(1) $F = a + bR + cZ + \mathbf{X}d + \mu$,

where F is the log of forest area, R is the log of the length of road networks the rural sector, Z is the log forest land cleared for agricultural purposes, **X** is a vector of other direct factors and μ is a random disturbance term. The coefficients b and c are the elasticities of road networks and agricultural land area on forest cover, respectively. We do not estimate equation (1), instead we use estimates from microstudies to derive parameters for b and c.

From Block I of the conceptual framework, we formulate and estimate equations that explain the effect of underlying factors on R and Z,

(2) $R_{it} = \beta_0 + \beta_1 Z_{i,t-1} + \beta_2 Y_{it} + \beta_3 Y_{it}^2 + \beta_4 Y_{it} C_{it} + \beta_5 Y_{it} S_{it} + \beta_6 C_{it} + \beta_7 S_{it} + \mathbf{A}\mathrm{B} + \delta_i + \chi_t + \eta_{it}$;

(3) $Z_{it} = \gamma_0 + \gamma_1 R_{i,t-1} + \gamma_2 Y_{it} + \gamma_3 Y_{it}^2 + \gamma_4 Y_{it} C_{it} + \gamma_5 Y_{it} S_{it} + \gamma_6 C_{it} + \gamma_7 S_{it} + \mathbf{B}\Gamma + \vartheta_i + \zeta_t + \varepsilon_{it}$;

where subscript *i* and *t* represents country and time, respectively and β_j and γ_j (j=0,..,7) are parameters. Thus, Y_{it} is log of gross domestic product per capita; C_{it} is a measure of log corruption control; S_{it} is a measure of log political stability; ϑ_i and δ_i are country effects which can be fixed or random, ζ_t and χ_y are time effects common to all countries; and ε_{it} and η_{it} are random disturbance. **A** and **B** are vectors of variables associated with the vector of parameters Β and Γ, respectively.

We categorize five factors affecting roads and agricultural land clearing: (1) income per capita; (2) measures of governance captured by political stability and corruption control; (3) macroeconomic policies; (4) unmeasured country-specific factors and (5) global economic conditions affecting all countries in a given time period. Because we are interested in examining if there exists a reasonable turning point on income per capita in relation to deforestation-induced CO_2 emissions, we specify income per capita squared in our model. Political stability and corruption control are our measures of governance and they affect our CO_2-income relationship by influencing the potential turning point and the pollution level.

The expansion of agricultural crop production into forested areas may not immediately induce an increase in the rural road network and rural road building may not immediately lead to agricultural land expansion. For this reason, agricultural expansion is lagged in equation (2) and road networks are lagged in equation (3).

Macroeconomic policies include trade policies, foreign direct investment and other country characteristics that change over time. Unmeasured country-specific factors are structural characteristics that change little, if at all, throughout time, such as climate, geographical conditions, and factor endowments. We use fixed or random effects to capture these variables. Lastly, global economic conditions are international shocks that are likely to affect all countries at the same time. We use time dummies to capture this effect.

The effect of income and governance on forest cover

The total effect of income on forest cover is,

(4) $$\frac{\partial F}{\partial Y} = b\frac{\partial R}{\partial Y} + c\frac{\partial Z}{\partial Y}.$$

The short-run effect of income on roads and agricultural land clearing are,[2]

(5) $$\frac{\partial R}{\partial Y} = \beta_2 + 2\beta_3 Y + \beta_4 C + \beta_5 S;$$

(6) $$\frac{\partial Z}{\partial Y} = \gamma_2 + 2\gamma_3 Y + \gamma_4 C + \gamma_5 S.$$

Using (5) and (6) into (4), we derive the total short-run effect of income per capita on forest cover. In the long run, the effect of any variable at time *t* is the same as time *t-1*. By simultaneously solving for (2) and (3), we obtain the long-run equation linking income to the direct factors of deforestation,

(7) $$\frac{dR}{dY} = \frac{\beta_2 + 2\beta_3 Y + \beta_4 C + \beta_5 S + \beta_1(\gamma_2 + 2\gamma_3 Y + \gamma_4 C + \gamma_5 S)}{1-\gamma\beta};$$

(8) $$\frac{dZ}{dY} = \frac{\gamma_2 + 2\gamma_3 Y + \gamma_4 C + \gamma_5 S + \gamma_1(\beta_2 + 2\beta_3 Y + \beta_4 C + \beta_5 S)}{1-\gamma_1\beta_1}.$$

Using (7) and (8) into (4), we derive the long-run effect of income on forest cover.

We hypothesize that the forest-income curve is a U-shaped relationship where initial increases in income result in a decrease in forest cover. It may reach a turning point, or per capita income level at which the slope of the forest-income relationship is zero, where any income level beyond it will yield an increase in forest cover. Even if a turning point does exist, it may not fall

[2] We drop the subscripts to minimize notation clutter.

within the credible ranges of per capita income for a particular country. A U-shaped relationship forest-income curve exists if the derivative of (4) with respect to income is positive.

The short-run turning point is derived by substituting (5) and (6) into (4) and equating (4) to zero to solve for *Y*. A similar procedure is conducted to derive the long-run turning points but now (7) and (8) are substituted into (4). The short-run, Y^t_{sr}, and long-run turning points, Y^t_{lr}, are expressed as,

$$(9)\quad Y^t_{sr} = -\frac{c(\gamma_2 + \gamma_4 C + \gamma_5 S) + b(\beta_2 + \beta_4 C + \beta_5 S)}{2(c\gamma_3 + b\beta_3)},$$

$$(10)\quad Y^t_{lr} = -\frac{c(\gamma_2 + \gamma_4 C + \gamma_5 S + \gamma_1(\beta_2 + \beta_4 C + \beta_5 S)) + b(\beta_2 + \beta_4 C + \beta_5 S + \beta_1(\gamma_2 + \gamma_4 C + \gamma_5 S))}{2(c(\gamma_3 + \gamma_1\beta_3) + b(\beta_1\gamma_3 + \beta_3))}.$$

The main difference in the short run and long run is the potential for road building and agricultural land clearing to affect each other in the latter but not in the former. If road networks and agricultural land demand are complements, the long run turning point is likely to be larger than the short run turning point, all other variables constant. However, if income reduces road infrastructure in the rural areas because of rural-urban migration or has a negative effect on agricultural land demand then it is difficult *a priori* to compare the short-run versus the long-run effects of income on forest cover.

Corruption control and political stability may affect the steepness of the forest-income curve as well as the turning point. If the current level of income is on the downward sloping portion of the forest-income curve, faster economic growth would mean faster deforestation with a steep forest-income curve. The effect of corruption control and political stability on the turning point will depend on the effect of both variables on income. If improvements in both governance variables induce economic growth, the turning point may be lower.

Corruption control and political stability may also have a direct effect on the level of forest cover. The level effects in the short run are derived by taking the derivative of (1) with respect to *C* and *S*,

(11) $$\frac{\partial F}{\partial C} = b(\beta_4 Y + \beta_6) + c(\gamma_4 Y + \gamma_6)\ ;$$

(12) $$\frac{\partial F}{\partial S} = b(\beta_5 Y + \beta_7) + c(\gamma_5 Y + \gamma_7)\ .$$

The long-run level effects are derived by simultaneously solving for (2) and (3) when *t* = *t-1*,

(13) $$\frac{\partial F}{\partial C} = b\left(\frac{\gamma_4 Y + \gamma_6 + \gamma_1(\beta_4 Y + \beta_6)}{1-\gamma_1\beta_1}\right) + c\left(\frac{\beta_4 Y + \beta_6 + \beta_1(\gamma_4 Y + \gamma_6)}{1-\gamma_1\beta_1}\right);$$

(14) $$\frac{\partial F}{\partial S} = b\left(\frac{\gamma_5 Y + \gamma_7 + \gamma_1(\beta_5 Y + \beta_7)}{1-\gamma_1\beta_1}\right) + c\left(\frac{\beta_5 Y + \beta_7 + \beta_1(\gamma_5 Y + \gamma_7)}{1-\gamma_1\beta_1}\right).$$

It is not clear *a priori* if the short-run effect is larger or smaller than the long-run effect since it will depend on the relationship between road building and agricultural land clearing as well as the indirect effects of the governance variables through income.

The effect of corruption control and political stability on carbon dioxide emissions

Total carbon dioxide emissions, *E*, is dependent on the change in forest cover and can be specified as,

(15) $$E = \Delta F \cdot \psi\ ,$$

where ψ is a conversion coefficient that estimates the amount of carbon dioxide sequestered or emitted from a change in forest area.

Naughton-Treves (2004) uses the following conversion coefficient formula,

(16) $\psi = B \cdot F \cdot E$,

where *B* is aboveground live biomass of forest megagrams per hectare (Mg/ha); *F* is the CO_2 fraction of dry biomass; and *E* is the burning efficiency of forest clearance, which refers to the percentage of heat content in the wood that can be extracted and used. Naughton-Treves (2004) uses different parameters for primary and secondary forests. For mature forests she uses values of 0.5 for *F* and 407 Mg/ha for *B*. The estimated value of *E* is 0.4 if reburning of primary forests occurs (Crutzen and Andreae, 1990). Estimated burning efficiency for fallow or secondary forests is at 0.6 but the CO_2 fraction of dry biomass remains the same. The biomass from fallow forest is equal to the average accumulation of aboveground biomass multiplied by the fallow period. Naughton-Treves (2004) assumes that biomass fallow is 11.5 Mg C/(ha year) and the average fallow period is 3.2 years.

The total change in forest cover depends on the summation of changes for each significant variable multiplied by the variable's partial effect on forest cover,

$$(17)\quad E = \sum_i \frac{\partial F}{\partial x_i} \Delta x_i \cdot \psi ,$$

where x_i is the i^{th} significant variable affecting forest cover. The amount of CO_2 flow attributed to changes in income, E_Y, only is

$$(18)\quad E_Y = \frac{\partial F}{\partial Y} \Delta Y \cdot \psi .$$

Using (4), (5) and (6) into (18), we can derive the short-run CO_2 emissions due to changes in income, E_Y^{SR}; and using (4), (7) and (8) into (18) we derive the long-run emissions, E_Y^{LR},

$$(19)\quad E_Y^{SR} = \left(b(\beta_2 + 2\beta_3 Y + \beta_4 C + \beta_5 S) + c(\gamma_2 + 2\gamma_3 Y + \gamma_4 C + \gamma_5 S) \right) \Delta Y \cdot \psi ;$$

$$(20)\quad E_Y^{LR} = \left(b\left(\frac{\beta_2 + 2\beta_3 Y + \beta_4 C + \beta_5 S + \beta_1(\gamma_2 + 2\gamma_3 Y + \gamma_4 C + \gamma_5 S)}{1 - \gamma_1 \beta_1} \right) + c\left(\frac{\gamma_2 + 2\gamma_3 Y + \gamma_4 C + \gamma_5 S + \gamma_1(\beta_2 + 2\beta_3 Y + \beta_4 C + \beta_5 S)}{1 - \gamma_1 \beta_1} \right) \right) \Delta Y \cdot \psi .$$

There are three important items to note linking the effect of income on deforestation-induced CO_2 emissions. First, the *level* effects of income may have an impact on forest cover but not CO_2 emissions. If there are no changes in income level, there will be no changes in forest level, all else constant; therefore there will be no CO_2 emissions. Only a *change* income can induce CO_2 emissions. Second, given a change in income, the carbon emissions level may also be affected by corruption control and political stability levels. Lastly, it is difficult to compare the short-run effect to the long-run effect of income given the interaction of road building and agricultural land clearing as well as economic growth, political stability and corruption control.

Hypotheses

From our empirical model, the following hypotheses are formulated and tested:

1. Countries with more political stability and less corruption will have higher forest levels in the short run and long run. This implies testing if equations (11) to (14) are positive.
2. The forest-income relationship is U-shaped in the long run and short run. This implies that at low income levels, an increase in income leads to a decrease in forest cover. However, after reaching a turning point, further increases in income lead to an increase in forest cover. For this to hold, the second derivative of income on forest cover must be positive, i.e. $\frac{\partial^2 F}{\partial Y^2} = b\frac{\partial^2 R}{\partial Y^2} + c\frac{\partial^2 Z}{\partial Y^2} > 0$.
3. The turning point is lower in more politically stable and less corrupt countries in the long run and short run. To test this hypothesis, we examine if the partial derivatives of (9) and (10) with respect to corruption control and political stability are negative.

3. Data description

The set of countries in our sample were selected based on the methodology of López et al. (2002) where developing countries with significant absolute and relative forest cover are identified. Furthermore, we focused only on countries where there is a prevalence of agricultural crop encroachment on forest land. There is consistent evidence of tropical deforestation in Latin America due to agriculture and pasture conversion practices (Houghton et al., 1991) while shifting cultivation is widespread in Asia, especially in Southeast Asian countries (Rerkasem et al., 2009).[3] Thus, we have twenty-two countries in our sample all from Latin America and Asia. Appendix 1 lists these countries and identifies crops that encroach on forest land.

Table 1 shows the descriptive statistics from our sample, covering the periods 1990 to 2003. The key variables in our study are agricultural cropland and roads encroaching on forest cover and two governance indices: political stability and corruption control. We calculated our own measure of cropland expansion by identifying crops encroaching on forested areas for each country in our sample. Crops are selected based on available reports and studies regarding the country's food/cash crops and forest resources. We add the total amount of harvested land area for each crop using data from FAOSTAT in each country. By creating this variable instead of using aggregate cropland area, we are able to avoid overestimating the effect of governance on cropland area encroaching on forest regions. We used unpaved road length in kilometers from the World Development Indicators because it is a common type of rural infrastructure that connects agricultural and forest land and precedes any paved road construction.

We obtained data from the International Country Risk Guide for the political stability and corruption control indices. Political stability assesses the government's ability to implement its programs and to stay in office and is composed of government unity, legislative strength and popular support. Scores range from 0 to 12 where a score of zero equates to low political stability. The corruption control index measures corruption within the political system. It captures financial corruption such as bribes for police protection, tax assessments, export/import licenses or loans; and insidious forms of corruption such as nepotism, job reservations, favor-for-favors and secret party funding. The score of the corruption index ranges between 0 and 6, where

[3] African countries were excluded in the study because deforestation is mainly driven by the collection and consumption of fuelwood (Ribot, 1999). Developing countries in Europe and developed countries were likewise excluded since the major cause of deforestation is land clearing for urban developments (EEA, 2006).

zero means low corruption control. Appendix 2 presents the definitions and data sources of all variables in the study.

4. Results

We present the regressions showing the effect of governance on cropland expansion and unpaved road development into forest areas. Next, we combine the estimates of our regressions with coefficients from studies that measure the effect of direct factors on forest cover. Lastly, we simulate the CO_2 emissions given changes in forest cover.

Underlying factors and direct factors of deforestation

Table 2 summarizes the effects of the underlying factors on two direct factors of deforestation: road building and agricultural crop expansion. The role of per capita income is highly significant on agricultural land clearing. Per capita income increases agricultural land clearing at a decreasing rate. On the other hand, per capita income has a consistent negative impact on unpaved road construction, albeit not as significant as agricultural land clearing. The negative effect indicates that unpaved road construction is an inferior infrastructure commodity.

Political stability has a negative and significant effect on agricultural land clearing which is consistent with our discussion where political stability may lead to more programs that protect natural resources thereby increasing the cost of agricultural land clearing. Political stability has a positive effect on road building which is also consistent with the idea that more stable governments can establish more public projects. Corruption control does not seem to have any direct significant effect on either of our direct factors of deforestation. However, a joint test on our corruption control variable and corruption control and income per capita interaction variable shows that they are jointly positive and significant in affecting agricultural land clearing. If land

and technology are complements, more corruption control could increase technological development and lead to agricultural extensification.

The total effect of underlying factors on forest cover

We integrate our regression estimates with parameter estimates from microstudies that use individual country survey statistics, remote sensing or GIS data to analyze the effect of direct factors on deforestation. There are only a few microstudies that have derived the long-run and short-run effects of forest-competing crop area and roads. We have chosen from this set those parameters that are most compatible with our estimates based on methodological estimation and availability of descriptive statistics. In order to create elasticities comparable with our estimates, we use the implied marginal effects from the studies we selected and calculate the elasticities of the direct factors on forest cover using average forest cover, average unpaved road levels and average crop area in our sample.

The short-run and long-run effects of crop area on forest cover were taken from two studies. To derive the short run elasticity, we use estimates from López (2000) who found that a one hectare increase in area cultivated results in 4.4 hectares (*has*) decrease in forest cover in rural villages in Western Ivory Coast. This marginal effect is larger than one because conversion of forest cover to agricultural land also requires additional clearing for human settlement, infrastructure and other related activities supporting agricultural production. We use estimates from Maertens et al. (2006) to derive the long-run effect of shifting cultivation on forest cover. They find that a one hectare increase in area of shifting cultivation in Indonesia from 1980 to 2001 yielded a decrease in forest cover by 0.88 *has*. The implied marginal effect is less than one in the long run possibly because abandoning the area could have led to re-growth of natural forest vegetation.

Panayotou and Sungsuwan (1994) measure the effect of road networks on forest cover in Thailand. They find that a one kilometer (km) increase in road networks decreases forest cover by 0.27 km^2. Unfortunately, we were not able to find any studies that estimated the long-run effects of road networks on forest cover, so we assume that the short-run and long-run effects of road building are the same in our calculation.

Table 3 summarizes the total effects of income per capita and our two measures of governance on forest cover are evaluated at the mean levels. The elasticity of income on forest cover is derived using equations (4), (5) and (6) in the short run and (4), (7) and (8) in the long run. The total short-run effect of income per capita on forest cover is negative and significant. Income per capita decreases forest cover through increased agricultural crop expansion but it has a tendency to increase forest cover by reducing unpaved road construction where the former effect outweighs the latter effect. We do not find any persistent effect of GDP on forest cover in the long run.

The average economic growth in Latin America over our sample countries is 1.61% while it is 3.27% in Asia. This growth would lead to a decrease in forest cover of about 0.06% and 0.13% in Latin America and Asia, respectively, in the short run. The actual rates of deforestation in Latin America and Asia are higher at 0.6% and 0.7%, respectively. Thus, income growth explains less than a quarter of deforestation. The combined impact of other policies such as governance, trade and foreign direct investment may explain other sources of deforestation.

The short-run and long-run effects of corruption control on forest cover are derived using equations (11) and (13), respectively. The impact of corruption control on forest cover is negative and significant in the short run and the long run. Although corruption control has an insignificant effect on road building, it has a significant negative effect on forest cover because it induces an increase in agricultural land clearing. One explanation is that more corruption control could induce technological innovation and, if technology and land are complements in production, could lead to more land clearing for agricultural purposes. In contrast, political stability increases forest cover in the short run and long run. There is a significant positive effect of political stability because it induces a reduction in agricultural land clearing. Interestingly, there is a significant lingering effect in the long run in both of our measures of governance on forest cover but the magnitude is smaller. This result highlights the potential structural impacts of governance on natural capital. Our results partially verify Hypothesis 1. We do find that more politically stable countries have higher levels of forest cover but countries with higher levels of corruption control have lower forest cover, all else constant.

In order to derive a clear picture of the effect of our governance variables on forest cover, we simulate the effect of corruption control and political stability for Brazil and Indonesia, the countries with the most tropical forest cover. If the corruption control level of Brazil and Indonesia improved to the same stringency as Costa Rica, the country with the highest measure of corruption control in our sample, we estimate a 0.7% and 2.2% decrease in forest cover from agricultural land expansion in the short run, respectively. If Brazil and Indonesia improved political stability to similar levels in China, the most politically stable country in our sample, we estimate an increase in forest cover by 0.3% and 0.2%, respectively, in the short run.

Turning Point in the Forest Income Curve

The income turning point we derive in the short run is approximately $2600, a value significantly lower than those calculated in other studies such as Cropper and Griffiths (1994). The average per capita income from our sample of countries is approximately $1500 which is lower than our estimated turning point. The long-run turning point is significantly lower than the short run turning point at $1200 as illustrated in Figure 2 and Figure 3. The take away point is not the magnitude themselves but the potential for lowering the turning point in the long run given the interaction of agricultural land clearing and unpaved road construction. However, caution must be taken in interpreting this result. If paved road construction substitutes for unpaved road construction, our long-run turning point value may even be higher than the short-run turning point level.

Table 4 summarizes the tests on the forest and CO_2 Environmental Kuznets Curves. Hypothesis 2, which tests if a U-shaped forest-income curve exists, is verified since we show that $\partial^2 F/\partial Y^2$, or the effect of income on additional forest cover from income, is positive and significant. The effect is more significant and positive in the short run than the long run which implies that there is a larger turning point confidence interval in the long run.

Hypothesis 3 regarding a lower turning point for politically stable and less corrupt countries is not statistically verified. We find a weak significant but positive effect of political stability on the turning point in the short run. Economic growth may complement the effect of political stability by increasing agricultural land expansion leading to a higher turning point.

The results from our hypothesis tests imply that we can derive forest-income curves in the short run and long run as illustrated in the top panel of Figures 2 and 3. In the short run, when there is more corruption control, the forest-income curve shifts down but the turning point does not change. As we move to the long run, the turning point is now lower and more corruption control still leads to a lower forest-income curve.

The effect of political stability on the forest-income curve is more complicated. In the short run, as countries become more politically stable, the forest-income curve shifts up and to the right, signifying an increase in forest cover, and a higher income turning point. In the long run, the turning point is lower and the forest-income curve shifts up as countries are more politically stable.

Carbon dioxide emissions and governance

Deforestation-induced CO_2 emissions are fundamentally different than industrial-related carbon dioxide emissions. In the latter, there are CO_2 emissions for a given level of income per capita, corruption control or government stability; however, in the former, emissions only occur if there are *changes* in these variables as shown in equation (17). Thus, for income per capita to have any effect on deforestation-induced CO_2 emissions, the country would need to be growing or contracting over time. If we have a U-shaped forest-income curve, the corresponding CO_2 emissions-income curve would be downward sloping and crosses the income-axis at the turning point. Any point to the left of the turning point implies that there are CO_2 emissions and to the right of the turning point, CO_2 is sequestered because of an increase in forest cover.

If a governance variable decreases the slope of the forest income curve, then CO_2 emissions are less responsive to income changes. We find that corruption control does not have any significant effect on the slope of the forest income curve in the short run or long run. Thus, the effect of corruption control on the CO_2 emissions-income curve is illustrated as such in the bottom panel of Figure 2.

Political stability has a more complicated effect. More political stability decreases the marginal effect of income on forest cover in the short run leading to a flatter slope of the forest-income curve. This implies that the CO_2 emissions levels will be lower for countries with more political stability given the same level of income. Also, since the turning point increases with more political stability, the CO_2 emissions-income curve shifts to the right. In the long run, the same curve shifts to the left because of a decrease in the income turning point.

We simulate the effect of carbon dioxide emissions caused by deforestation in the 1990s using equation (18) and summarize the results in Table 5. Across all countries in our sample, carbon dioxide emissions from deforestation explain about 4.7% of total carbon dioxide emissions. We break down the sample into two: countries that have more than 30 million *has* of primary forest and those that have less than 30 million *has*. Countries that have at least 30 million *has* of primary forest release about 33% of their CO_2 emissions from deforestation. Thus, forest clearing explains a significant share of total CO_2 emissions in countries that have large remaining primary forests. For countries that have less than 30 million *has* of primary forest, we find a net uptake instead of a release in CO_2. Among the countries in this subset, China has seen a decrease in primary forest cover but it has been compensated by a significant increase in secondary forest from 1990 to 2000 leading to a net CO_2 uptake. If we leave China out of the sample, we find a decrease of 1000 *has* of forest cover which implies that deforestation accounts for 2% of total CO_2 emissions for the remaining countries in the sample.

Economic growth explains 23% or approximately 3.3 million Mg per annum of deforestation-induced CO_2 emissions. For countries that have more than 30 million *has* of primary forest and those that have less than 30 million *has*, economic growth explains 13% and 28% of deforestation-induced CO_2 emissions, respectively. This implies that the net effect of all non-growth factors is to exacerbate deforestation and corresponding CO_2 emissions.

The average corruption control levels have decreased for countries in our sample. The largest decreases came from countries with more than 30 million has of primary forest. We find CO_2 uptake because decreased corruption control has a positive effect on forest cover. Corruption control accounts for 0.1% of deforestation-induced CO_2 emissions.

Political stability has increased for countries in our sample. More stable government leads to more forest cover and, therefore, CO_2 uptake. There is a larger amount of variation explained by political stability compared to corruption control because it accounts for 7% of deforestation-induced CO_2 emissions.

5. Conclusion

The main objective of this article is to determine the effect of income per capita, political stability and corruption control on the forest-income relationship and the corresponding CO_2 emissions-income curve using a structural empirical model. Income per capita has a negative and significant impact on forest cover in the short run but does not have any lingering effects in the long run. In contrast, we do find that more politically stable countries have higher levels of forest cover but countries with higher levels of corruption control do not have higher forest cover. The effects of both governance variables are persistent since their effects continue in the long run albeit at a smaller magnitude.

A U-shaped forest-income curve exists. Political stability and corruption control do not lower the turning point. The resulting deforestation-induced CO_2 emission-income curve is downward sloping and is based on *changes* in income per capita affecting forest cover. More political stability flattens the CO_2 emissions-income curve in the short run leading to less responsive CO_2 emissions given changes in income.

One limitation of our current model is that we focus only on two direct causes of deforestation: cropland expansion and road building. We do not include other potential channels of deforestation such as logging and rural poverty. A future study may want to examine the total effects of including other potential channels and verify how the income and governance effects may differ through these channels. If the effect of income and the governance variables on other direct factors are in the same direction as cropland expansion and road building, we are likely to see a more pronounced U-shaped forest-income curve with a higher turning point. On the other hand, the net effects may be more difficult to hypothesize if there are countervailing effects across different direct channels.

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Tables

Table 1. *Summary statistics of variables*

Variable	*Mean*	*Std. Dev.*	*Min*	*Max*
Crop, area harvested (ha)	761,937.64	10.28	2,000.00	39,624,968.69
GDP per capita ($)	1,477.85	2.29	270.40	5,934.99
Crop price index	1.10	5.81	0.02	9,207.08
Foreign direct investment	2.64	2.37	-2.76	12.88
Political stability index	7.53	2.01	3.00	11.00
Corruption control index	2.91	0.92	1.00	5.00
Trade openness	0.85	33.42	-57.64	162.67
Unpaved road (km)	56,261.18	4.98	861.05	1,795,851.79
Investment price	54.23	1.39	15.36	105.14

Table 2. *Determinants of cropland area and unpaved roads in developing countries*

Dependent variable	*Log of cropland area*				*Log of unpaved roads*			
Variables	*OLS*	*TWFE*	*RE*	*HTRE*	*OLS*	*TWFE*	*RE*	*HTRE*
Lag of log crop land					0.546***	0.688	0.566***	0.646***
					(0.033)	(0.492)	(0.119)	(0.107)
Lag of log unpaved roads	1.138***	0.115***	0.155***	0.121***				
	(0.069)	(0.025)	(0.033)	(0.032)				
Log of GDP per capita	20.403***	3.594***	3.509***	3.582***	-17.156***	-0.848	-3.008*	-1.436
	(1.883)	(0.995)	(1.148)	(1.059)	(1.141)	(4.842)	(2.086)	(2.102)
Log of GDP per capita squared	-1.410***	-0.220***	-0.210***	-0.218***	1.187***	-0.062	0.130	-0.009
	(0.149)	(0.075)	(0.081)	(0.073)	(0.085)	(0.288)	(0.140)	(0.144)
Log of investment price index					0.557*	0.047	0.041	0.039
					(0.376)	(0.144)	(0.104)	(0.135)
Log of crop price index	0.116***	0.005	0.005	0.005				
	(0.025)	(0.006)	(0.006)	(0.007)				
Foreign direct investment over GDP	-0.159***	-0.009	-0.009*	-0.009**	0.025	0.026***	0.028***	0.026***
	(0.052)	(0.008)	(0.006)	(0.005)	(0.029)	(0.010)	(0.010)	(0.010)
Corruption control	-3.048***	0.104	0.109	0.106	1.029***	-0.253	-0.288	-0.263
	(0.988)	(0.239)	(0.180)	(0.142)	(0.478)	(0.356)	(0.261)	(0.285)
Log of GDP per capita *x* Corruption control	0.279***	-0.005	-0.007	-0.006	-0.080	0.033	0.039	0.035
	(0.134)	(0.032)	(0.024)	(0.020)	(0.065)	(0.047)	(0.036)	(0.040)
Political stability	-0.309	-0.075**	-0.074*	-0.075**	0.704***	0.022	0.106*	0.044
	(0.373)	(0.043)	(0.051)	(0.043)	(0.218)	(0.101)	(0.071)	(0.091)
Log of GDP per capita *x* Political stability	0.074	0.008	0.008	0.008	-0.104***	-0.001	-0.014	-0.005
	(0.052)	(0.006)	(0.007)	(0.006)	(0.031)	(0.012)	(0.010)	(0.012)
Index of trade openness	0.021***	0.001	0.001	0.001	-0.011***	-0.0001	-0.001	-0.0004
	(0.003)	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)	(0.002)
Constant	-71.523***	-1.908	-2.028	-2.363	61.545***	10.800	17.853***	11.976*
	(6.568)	(3.395)	(4.082)	(3.981)	(3.602)	(16.606)	(7.100)	(7.569)
R-squared	0.741	0.175	0.221		0.733	0.350	0.428	
Number of observations	227	227	227	251	251	251	251	251
Annual dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Hausman test (prob Chi-squared)			(-)				0.46	

Notes: Robust standard errors.

*** 5%, **10%, *15% levels of significance

Table 3. *Total effect of GDP and governance on forest cover*

	Crop channel		*Road channel*		*Total effect*	
Short run	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
GDP	-0.061	0.074	0.022**	0.017	-0.040*	0.033
Corruption Control	-0.017***	0.009	-0.0003	0.001	-0.017***	0.009
Political Stability	0.004**	0.002	0.00001	0.0003	0.004**	0.003
Long run						
GDP	-0.007	0.015	0.020*	0.016	0.013	0.025
Corruption Control	-0.004***	0.002	-0.001	0.001	-0.005**	0.003
Political Stability	0.001**	0.0005	0.0002	0.0004	0.001**	0.0008

Note: *** 5%, ** 10%, *15% levels of significance

Table 4. *Tests on forest–income curve and CO_2 emissions–income curve properties*

Forest–income curve properties	*Short run*	*Long run*
Effect of income on marginal forest cover from income	0.112***	0.023*
	(0.041)	(0.018)
Effect of corruption control on turning point	-0.005	0.035
	(0.076)	(0.120)
Effect of political stability on turning point	0.016*	0.005
	(0.013)	(0.022)
CO_2 emissions–income curve properties		
Effect of corruption control on marginal forest cover from income	0.001	-0.001
	(0.009)	(0.003)
Effect of political stability on marginal forest cover from income	-0.002*	-0.0001
	(0.002)	(0.001)

Note: *** 5%, ** 10%, *15% levels of significance

Table 5. *Estimated annual CO_2 emissions due to growth in GDP, corruption control and government stability*

	Countries with more than 30 million ha of primary forest	Countries with less than 30 million ha of primary forest	All countries in sample
Estimated Annual Carbon Dioxide Emissions From the Industrial Sector in 1000 Mg	117,521	357,031	292,162
Estimated Annual Carbon Dioxide Release From Forest Clearing in 1000 Mg (as percent of total carbon emissions)	58,500 (33.2)	-1,667 (0.5)	14,290 (4.7)
Effect of economic growth			
Average Annual Growth of GDP Per Capita (%)	2.0	2.4	2.3
Estimated Annual Carbon Dioxide Release From Forest Clearing in 1000 Mg (as percent of total carbon emissions from deforestation)	7,486 (12.8)	468 (28.1)	3,345 (23.4)
Effect of corruption control			
Average Annual percentage change in corruption control (%)	-1.0	-0.1	-0.4
Estimated Annual Carbon Dioxide Release From Forest Clearing in 1000 Mg (as percent of total carbon emissions from deforestation)	-1,660 (2.8)	-6 (0.4)	-217 (0.1)
Effect of government stability			
Average Annual percentage change in government stability (%)	3.7	7.9	6.7
Estimated Annual Carbon Dioxide Release From Forest Clearing in 1000 Mg (as percent of total carbon emissions from deforestation)	-1,391 (2.4)	-152 (9.2)	-971 (6.8)

Note: Short-run parameter estimates are used in the simulations.

Figures

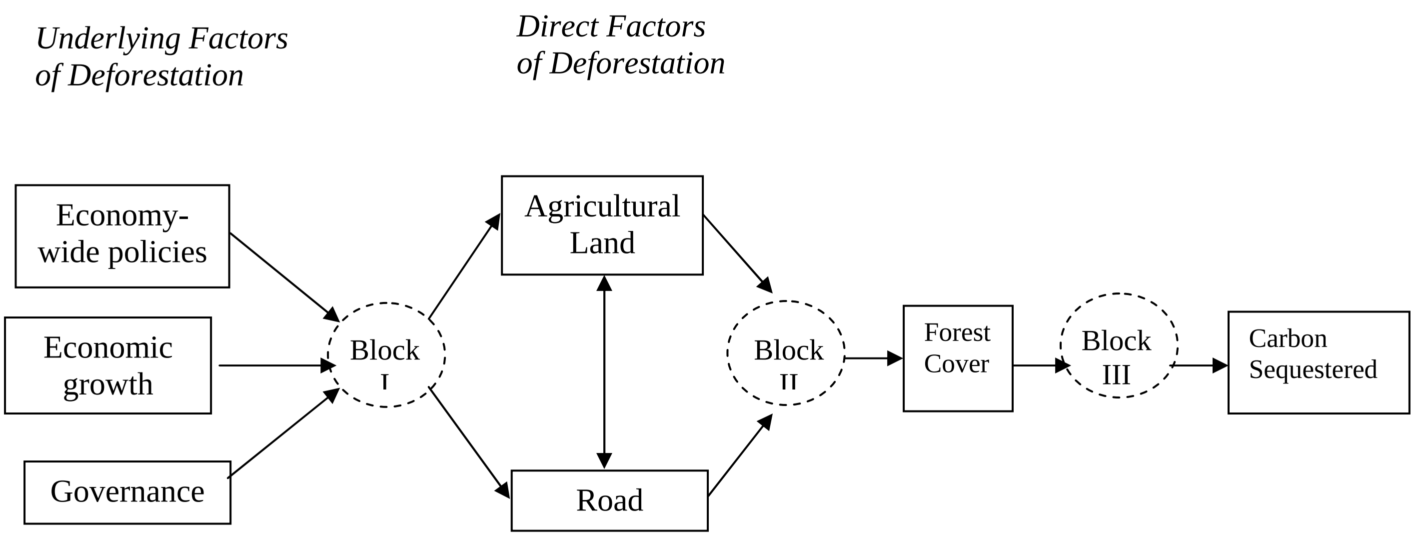

Figure 1. *Linking deforestation-related carbon dioxide emissions to governance and economic growth.*

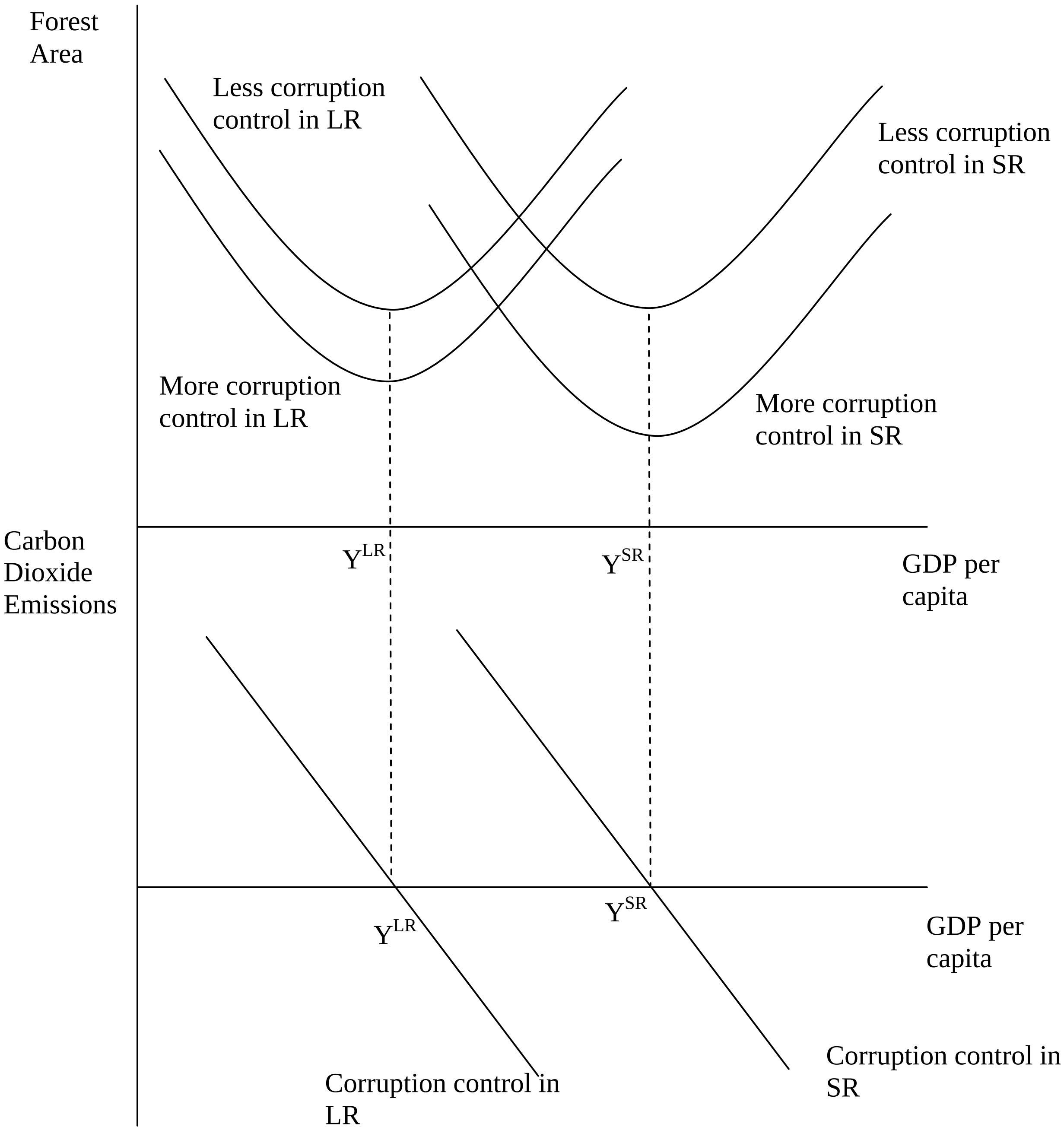

Figure 2. *Effect of corruption control on forest cover-income curve and CO_2 emissions-income curve in the short run (SR) and long run (LR).*

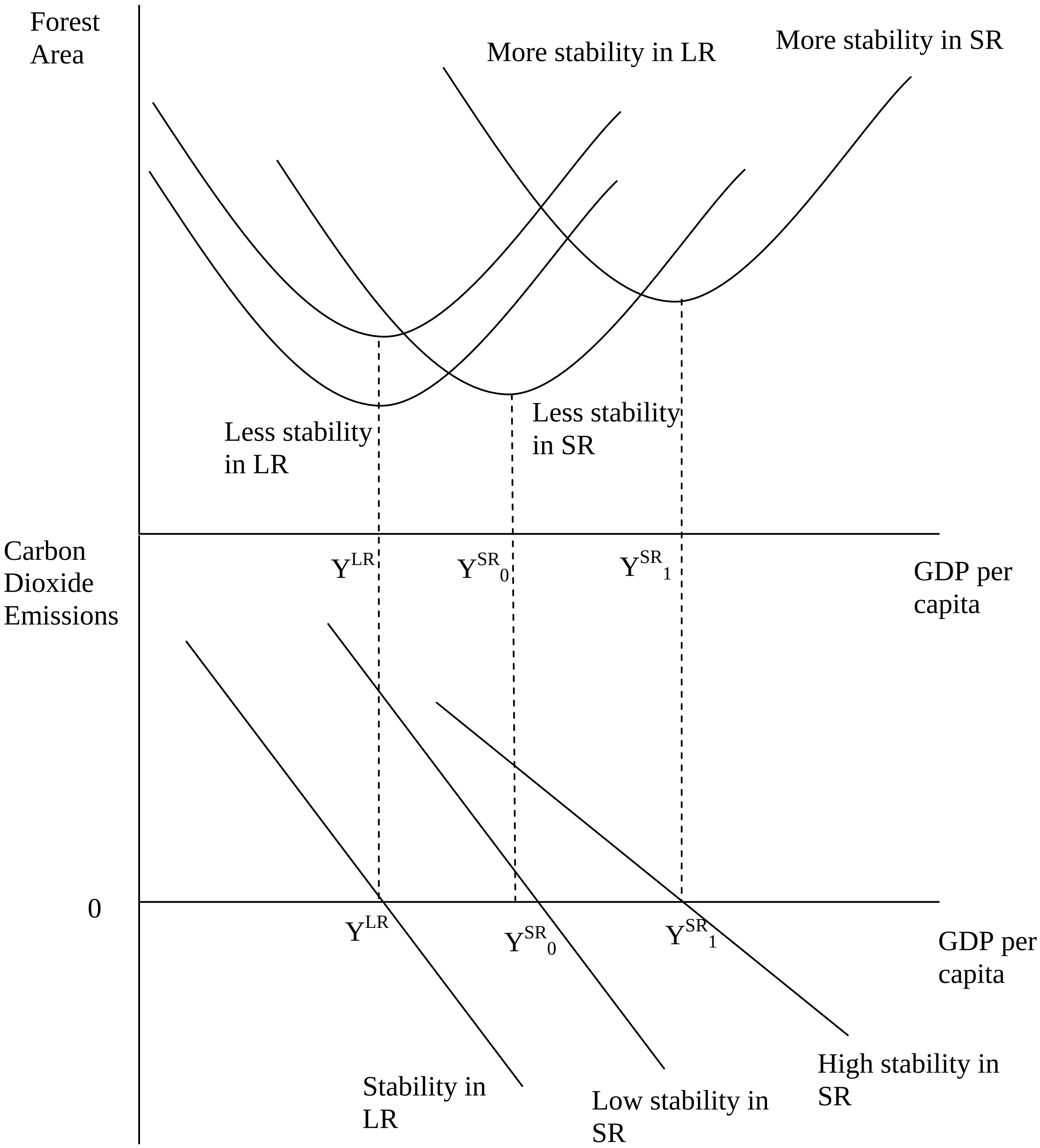

Figure 3. *Effect of political stability on forest-income curve and CO_2 emissions-income curve in the short run (SR) and long run (LR).*

APPENDIX 1

LIST OF COUNTRIES AND AGRICULTURAL CROPS ENCROACHING ON FOREST LAND

Country	Crop/s	Source/s
Bangladesh	Oilseeds, rubber, cotton	Golam Rasul. 2007. “Political Ecology of Degradation of Forest Common in the Chittagong Hill Tracts of Bangladesh.” Environmental Conservation 34 (2): 153–163.
Bolivia	Quinoa, fava bean, maize, maize green, potato, barley, soybeans	Bluffstone, R., M. Boscolo and R. Molina. 2002. “How does community forestry affect rural households: A labor allocation model of the Bolivian Andes.” See Table 6. Available from: http://dlc.dlib.indiana.edu/dlc/handle/10535/985 World Rainforest Movement. 2004. “The Focus of this Issue: The Role of Agriculture and Cattle Raising in Deforestation.” Issue Number 85. Available from: http://www.wrm.org.uy/bulletin/85/viewpoint.html.
Brazil	Banana, coffee, maize, rice, soybeans, cassava/tapioca, beans (including cowpeas and other types)	López, R. and G. I. Galinato. 2005. “Trade Policies, Economic Growth, and the Direct Causes of Deforestation.” Land Economics 81 (2): 145-169. Simon, M.F. and F.L. Garagorry. 2005. "The expansion of agriculture in the Brazilian Amazon." Environmental Conservation 32 (3): 203–212.
China	Soybeans	World Rainforest Movement. 2004. “The Focus of this Issue: The Role of Agriculture and Cattle Raising in Deforestation.” Issue Number 85. Available from: http://www.wrm.org.uy/bulletin/85/viewpoint.html.
Colombia	Banana, arrowleaf, new cocoyam, maize, pineapple, sugar cane, cassava/manioc	Eden, M.J. and A. Andrade. 1988. "Colonos, Agriculture and Adaptation in the Colombian Amazon." Journal of Biogeography 15(1): 79-85.
Costa Rica	Banana, mango	Christian, S. 1992. "There's a Bonanza in Nature for Costa Rica, but Its Forests Too Are Besieged." The New York Times. Available from: http://www.nytimes.com/1992/05/29/world/there-s-a-bonanza-in-nature-for-costa-rica-but-its-forests-too-are-besieged.html.
Dominican Republic	Coffee, corn	Rosa, H. 2004. “Economic Integration and the Environment in El Salvador.” Working Group on Development and Environment in the Americas, Discussion Paper No. 7. Available from: http://ase.tufts.edu/gdae/pubs/rp/DP07RosaJuly04.pdf.
Ecuador	Cacao, coffee, manioc/cassava, naranjilla, tea, palm oil, rice, maize	Schaller et al. no date. “Indigenous Ecotourism and Sustainable Development: The Case of Río Blanco, Ecuador.” http://www.eduweb.com/schaller/Section1RioBlanco1.html

Country	Crop/s	Source/s
Honduras	Beans, coffee, maize	Tucker, C.M., D.K. Munroe, H. Nagendra and J. Southworth. 2005. “Comparative Spatial Analyses of Forest Conservation and Change in Honduras and Guatemala.” Conservation and Society 3(1): 174 - 200.
India	Soybeans	World Rainforest Movement. 2004. “The Focus of this Issue: The Role of Agriculture and Cattle Raising in Deforestation.” Issue Number 85. Available from: http://www.wrm.org.uy/bulletin/85/viewpoint.html.
Indonesia	Coconut, rubber, palm oil	López, R. and G. I. Galinato. 2005. “Trade Policies, Economic Growth, and the Direct Causes of Deforestation.” Land Economics 81(2): 145-169. World Rainforest Movement. 2004. “The Focus of this Issue: The Role of Agriculture and Cattle Raising in Deforestation.” Issue Number 85. Available from: http://www.wrm.org.uy/bulletin/85/viewpoint.html.
Iran, Islamic Rep.	Wheat	Subregional report of the Forestry Outlook Study for West and Central Asia. Available from: ftp://ftp.fao.org/docrep/fao/010/k1652e/k1652e03.pdf.
Malaysia	Coconut, rubber, palm oil, rice	López, R. and G. I. Galinato. 2005. “Trade Policies, Economic Growth, and the Direct Causes of Deforestation.” Land Economics 81(2): 145-169. World Rainforest Movement. 2004. “The Focus of this Issue: The Role of Agriculture and Cattle Raising in Deforestation.” Issue Number 85. Available from: http://www.wrm.org.uy/bulletin/85/viewpoint.html.
Mexico	Maize, commercial chili	Deininger, K.W. and B. Minten. 1999. “Poverty, policies, and deforestation: The case of Mexico.” World Bank Research Paper. Available from: http://www.journals.uchicago.edu/cgi-bin/resolve?EDCCv47p313PS. Turner, B. L., II, P.A. Matson, J.J. McCarthy, R.W. Corell, L.Christensen, N. Eckley, G. Hovelsrud-Broda, J.X. Kasperson, R.E. Kasperson, A. Luers, M.L. Martello, S. Mathiesen, R. Naylor, C. Polsky, A. Pulsipher, A. Schiller, H. Selin, and N. Tyler. 2003. “Illustrating the Coupled Human-Environment System for Vulnerability Analysis: Three Case Studies.” Proceedings of the National Academy of Sciences of the United States of America 100(14): 8080-8085. Available from: http://ksgnotes1.harvard.edu/BCSIA/sust.nsf/pubs/pub83.
Nicaragua	Palm fruit	From Meals to Wheels: The Social and Ecological Catastrophe of Biofuels. Available from: http://www.globaljusticeecology.org/files/GJEP-biofuels-comp.pdf.

Country	Crop/s	Source/s
Pakistan	Sugar cane	Abbas, M. , S.H. Khan, R.A. Khan and M. Shahbaz. 2004. "Impact of Wild Boar Habitat on Sugarcane Crop." International Journal of Agriculture and Biology 6(2): 420-421.
Panama	Coffee	Beatty, A. 2008. Gourmet Coffee Eats into Panama Forest. Reuters Article. Available from: http://www.reuters.com/article/environmentNews/idUSN2233936820080723.
Peru	Cassava/tapioca, peach palm, maize, plantains, rice	Staver, C., R. Simeone and A. Stocks. 1994. "Land Resource Management and Forest Conservation in Central Amazonian Peru: Regional, Community, and Farm-Level Approaches among Native Peoples." Mountain Research and Development 14(2): 147-157.
Philippines	Cassava, corn, rice, sweet potato	Honda, Y. 1997. "Philippine Sugar and Environment." TED Case Studies No. 250, American University. Available from: http://www.american.edu/TED/PHILSUG.HTM. López, R. and G. I. Galinato. 2005. "Trade Policies, Economic Growth, and the Direct Causes of Deforestation." Land Economics 81(2): 145-169.
Sri Lanka	Tobacco, banana, coconut, mango	C. Bogahawatte. 2003. "Forestry Policy, Non-Timber Forest Products and The Rural Economy In The Wet Zone in Sri Lanka." Economy and Environment Program for Southeast Asia (EEPSEA) Research Report. Available from: http://ideas.repec.org/p/eep/report/rr1999122.html.
Thailand	Cassava	P. Macek and K. Chareonying. 1997. "Thailand's Logging Ban." TED Case Studies No. 69, American University. Available from: http://www.american.edu/TED/THAILOG.HTM.
Venezuela, RB	Banana, coffee, maize, tobacco, cassava, sugar cane, citrus fruit	Allan, J. D., A. J. Brenner, J. Erazo, L. Fernandez, A. S. Flecker, D. L. Karwan, Samuel Segnini, D. C. Taphorn. 2002. "Land Use in Watersheds of the Venezuelan Andes: a Comparative Analysis." Conservation Biology 16(2): 527-538.

Note: Agricultural crops encroaching on forest land refer to crops identified in studies that are planted along shifting agricultural frontiers converted from forest land.

Appendix 2. *Definition and sources of variables used in the study*

Variable name	*Definition*	*Source/s*
Crop, area harvested (ha)	Area harvested in hectares	Author's calculation using data from FAOSTAT – Production.[a]
GDP per capita (constant 2000 $)	Gross domestic product divided by total population	World Development Indicators[b]
Crop price index	Calculation is based on the Laspeyres index formula: $P = \frac{\sum(p_c t_n \times q_c t_0)}{\sum(p_c t_0 \times q_c t_0)}$ where P is the change in price level, p_c,t represents the prevailing price of crop c in period t, q_c,t is the quantity of crop c sold in period t, t_0 is the base period (year 2000), and t_n is the period for which the index is computed.	Author's calculation using data from FAOSTAT – Production (Crops) database and FAOSTAT - Production (PriceSTAT) database.[a]
Foreign direct investment	As percentage of GDP.	World Development Indicators[b]
Government political stability index	Assesses the government's ability to implement its programs and to stay in office.	The PRS Group, Inc.[c]
Corruption control index	An indicator of corruption within the political system, characterized by financial corruption and insidious corruption.	The PRS Group, Inc. [c]
Trade openness	See source.	López et al. (2002)
Unpaved road (km)	Length of unpaved road network	World Development Indicators[b]
Price level of investment	Calculated as Purchasing Power Parity (PPP) over Investment divided by the exchange rate times 100.	Penn World Tables[d]

[a] Food and Agriculture Organization of the United Nations (FAO). 2009. FAOSTAT – Production (Crops) and Prices (PriceSTAT) databases. Available from: http://faostat.fao.org/.
[b] World Bank. 2009. World Development Indicators. Washington, DC.
[c] The PRS Group, Inc. 2009. International Country Risk Guide. Available from: http://www.prsgroup.com/ICRG.aspx.
[d] Center for International Comparisons of Production, Income and Prices (CIC). 2006. Penn World Tables 6.3. Available from: http://pwt.econ.upenn.edu/php_site/pwt63/pwt63_form.php.