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ABSTRACT. This article examines how governance, particularly corruption control and politically stability, affects deforestation due to agricultural land expansion. The theoretical model shows the importance of the complementarity or substitutability of technology and land use in determining the effect of governance on forest cover *vis-à-vis* agricultural land expansion. We estimate a structural empirical model to measure the effect of corruption control and political stability on deforestation in developing countries. Political stability has a positive and significant effect on forest cover; however, corruption control has a negative and significant effect on forest cover because technological development induces increased agricultural land expansion.

I. INTRODUCTION

The determinants of deforestation are categorized as direct factors and underlying factors of deforestation. Direct factors, such as logging, agricultural land expansion and road building, immediately contribute to the conversion of forest land to other land uses while underlying factors influence the severity of the direct factors. Many underlying factors have been analyzed such as economic growth (Koop and Tole 1999), political institutions (Nguyen Van and Azomahou 2007), exchange rates (Arcand et al. 2008), trade openness (López and Galinato 2005), poverty (Zwane 2007), population, market forces and property rights (Angelsen 1999).

Understanding the effect of governance on economic growth has become a central focus in the literature (World Bank 2002). Weak institutions due to corruption, political instability or lack of regulations can hinder economic development. Corruption and political instability at the national level can impede rural development by reducing public expenditure (Anriquez 2007). Corruption also skews policies in favor of rent seeking firms (Bulte and Damania 2008) and political instability creates uncertainty that leads to less resource conservation (Deacon and Mueller 2004) and a reduction in resource stocks.

This article examines the effect of governance, particularly corruption control and political stability, on forest cover in developing countries. We develop a theoretical model that explains how governance affects deforestation due to agricultural land expansion. We test our theoretical results by estimating a structural empirical model to measure the effect of corruption control and political stability on deforestation in developing countries through two direct channels of deforestation: agricultural land expansion and road building.[1] The theoretical model explains the underlying mechanisms by which governance affects deforestation while the empirical model provides a measure relating governance and deforestation through the direct channels in the short run and long run. The empirical analysis has important policy implications because it measures the immediate and long term importance of controlling corruption and correcting political instability on forests and, consequently rural development.

We develop a two-stage model where a profit-maximizing representative farmer selects the optimal amount of agricultural land to be cleared given the available technology in the agricultural sector. Next, given the choice of the representative farmer, the government chooses the level of infrastructure development projects in the rural economy. We find that the substitutability or complementarity of technology and land use play a significant role in determining the effect of corruption control and political stability on agricultural land use and, subsequently forest cover.

We define political stability as a measure of the probability that the government is overthrown. This measure of governance enters into our model in two ways. 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. The first assumption we make is that political stability influences the probability of completing rural infrastructure programs. We also assume that political stability affects the cost of land clearing but the relationship depends on the stringency of forest protection laws.

Corruption control enters into our model in two ways. First, corruption increases the cost of infrastructure building (Kenny 2006) which affects road building in the rural economy. Second, corruption affects the set of technologies available for the farmer in the agricultural sector. Bridgman et al. (2007) shows lobby groups have an incentive to block the adoption of superior technology in order to maximize rents. Similarly, Bulte et al. (2007) develops a model that shows how lobbying by wealthy farmers induces policy makers to select inefficient modes of agricultural production. Thus, we assume an increase in corruption control increases available technology in the agricultural sector. Agricultural technology choice significantly determines the extent to which deforestation occurs (Angelsen and Kaimowitz 2001). We show how corruption could lead to agricultural intensification or extensification depending on the complementarity or substitutability of land and technology.

We complement our theoretical model with an empirical analysis that measures the effects of governance on forest cover. Most empirical models that estimate the effect of macroeconomic variables on forest cover use a cross-country, reduced form approach (Cropper and Griffiths 1994; Shafik 1994; Southgate 1994; Antle and Heidebrink 1995; Deacon 1999; Koop and Tole 1999; Barbier and Burgess 1997, 2001). There are two significant criticisms with regard to this approach. First, a reduced form approach does not disentangle the channels by which such variables affect deforestation. By not modeling the channels through which governance affects deforestation, appropriate policies may not be identified. Second, all cross-country forest data rely on projected and interpolated data from the Food and Agricultural Organization (FAO). Two prominent analysts have concluded that FAO forest cover data is unsatisfactory in implementing some types of econometric analysis of deforestation (Angelsen and Kaimowitz 1999).

A number of microstudies that analyze the determinants of deforestation have relied on data from local surveys, remote sensing and satellite images (Panayotou and Sungsuwan 1994; Chomitz and Thomas 2003; Cropper et al. 2001; López 1997 and 2000). An advantage of these types of studies is the strong quality of forest cover data and direct factors data. Unfortunately, given the local nature of the data, it is difficult to analyze the effect of macroeconomic variables. López and Galinato (2005) were the first to develop a methodology to bridge the link between macroeconomic analyses with estimates from micro studies using four countries. They combine the elasticities from their regressions on direct factors of deforestation with parameter estimates from microstudies where direct factors are regressors to obtain the total effect of macroeconomic variables on forest cover.

Our study differs from the above-mentioned studies because we account for the effect of macroeconomic variables on deforestation through the direct factors of deforestation. Furthermore, we extend the empirical methodology of López and Galinato. First, we focus our analysis on the effect of two governance indicators: political stability and corruption control, on deforestation. Second, we extend the number of countries in our sample by creating a unique dataset that isolates the amount of agricultural land encroaching on forest cover. Lastly, we measure the short-run and long-run effect of macroeconomic variables on deforestation. This is the first study we are aware of that compares the long run and short run effects of underlying factors on forest cover.

The rest of the article is organized as follows: Section 2 presents the theoretical and empirical model. Section 3 describes the data. Section 4 presents the results of the regressions and the total effect of macroeconomic variables on deforestation. Section 5 concludes the study.

II. MODEL

We present a conceptual framework for the article. Next, we formulate the theoretical model which serves as the foundation for the empirical model.

Conceptual Framework

Micro studies of deforestation have identified land use patterns as the most important source of deforestation (Panayotou and Sungsuwan 1994; Pfaff 1999; López 1997 and 2000; Chomitz and Thomas 2003; Cropper, et al. 2001). Expansion of agriculture and construction of roads into forest areas are the most important direct factors determining deforestation especially in Latin America and Asia (Houghton et al. 1991; Rerkasem et al. 2009). Henceforth, we use the term agricultural land expansion and cropland expansion interchangeably. There may be a bi-causal relationship between agricultural land expansion and road building. Road construction in forest regions induces rural population development and land clearing for agricultural purposes. Also, agricultural expansion can lead to increased lobbying to develop rural infrastructure. Logging has its own dynamics, but initial logging is usually followed by agricultural expansion making it difficult to separate the effect of logging from agricultural expansion.

Figure 1 describes the conceptual framework that we develop to analyze the effects of governance on forest cover. Governance and other economy-wide policies are considered underlying factors. We focus on two direct factors of deforestation: agricultural land expansion and road building. Changes in governance affect agricultural land expansion and road infrastructure in the rural sector, which affect forest cover. There are two blocks of causation. Block I shows the effects from the underlying factors on the direct factors of deforestation. We present a theoretical model in the next subsection that outlines the mechanisms by which political stability and corruption control affect agricultural land expansion and road building. We measure the short run and long run effect of the two governance measures on the two direct factors of deforestation. Block II shows the effect of direct factors on forest cover. We rely on micro studies that estimate the impact of agricultural land expansion and road building on forest cover. We measure the total effect of governance on forest cover by combining our original regression coefficients and estimates from micro studies.

Theoretical Model of Governance, Agricultural Land Expansion and Road Building

Our objective in this subsection is not to derive unambiguous comparative static relating governance to agricultural land expansion and road building. Instead, we try to explain how governance influences these two direct factors of deforestation and derive a model that can be estimated empirically.

We specify an aggregate agricultural production function in the rural economy,

(1) $Q = F(Z, \mathbf{K}; A)$

where Q is agricultural output in the sector, Z is forest land area cleared for agriculture, $\mathbf{K}$ is a vector of physical inputs in the production of agricultural output and A is a technological productivity index. We assume that Q is concave and linearly homogeneous in all inputs.

Gross Domestic Product (GDP) in the agricultural sector or value added from the agricultural sector is defined as the returns to converted land, Z, such that

(2) $$G(p, \mathbf{w}, Z; A) \equiv \max_{\mathbf{K}} \{pF(Z, \mathbf{K}; A) - \mathbf{wK}\}$$

where $G(\cdot)$ is agricultural GDP, p is output price and $\mathbf{w}$ is a vector of competitive input prices associated with $\mathbf{K}$ that are determined in the world market. Agricultural GDP is a dual revenue function and is concave and increasing in Z (Diewert 1974).

Following Chomitz and Gray (1996), we postulate that differences in output prices are related to differences in transportation costs. The availability of roads affects market accessibility and can, therefore, influence prices. Thus, output prices depend on the amount of roads in the agricultural sector,

(3) $p=p(R)$

where R is the length of road networks in the rural sector. Road building is likely to reduce transportation distance leading to a decrease in output price (Chomitz and Gray 1996). Thus, we assume output price is decreasing at an increasing rate in the amount of road networks, such that $p_R(R) < 0$ and $p_{RR}(R) > 0$.[2]

The technology productivity index, A, is affected by government policies and the corruption control level,

(4) $A = A(\mathbf{H};\ \phi)$

where **H** is a vector of macroeconomic policies and indicators and ϕ is a measure of corruption control within a country. Corruption control is likely to have a positive effect on technology. If a coalition of firms lobby the government to prevent adoption of a superior technology by other firms in a sector, technological productivity in an economy decreases (Bridgman et al. 2007). Thus, technological productivity is non-decreasing in corruption control such that $A_\phi \geq 0$. Macroeconomic variables can have varying effects of technological developments depending on the specific policy.

Using (4) and (3) into (2), we derive the agricultural GDP function in the rural sector,

(5) $G(R, Z, \mathbf{w}, \mathbf{H};\ \phi)$.

There are several properties of the agricultural GDP function given our assumption on the effect of roads on output prices along with the production function characteristics. First, $G(\cdot)$ is increasing at a decreasing rate in Z which implies that $G_Z(\cdot) > 0$ and $G_{ZZ}(\cdot) < 0$, but decreasing at an increasing rate in R such that $G_R(\cdot) < 0$ and $G_{RR}(\cdot) > 0$ and the cross partial $G_{ZR}(\cdot) < 0$.

Based on our assumptions, the effect of corruption control on the marginal productivity of rural roads in the agricultural sector is non-increasing,

(6) $G_{R\phi}(R, Z, \mathbf{w}, \mathbf{H}; \phi) = p_R F_A A_\phi \leq 0$,

where F_A is the marginal product of technology and is non-decreasing. In contrast the effect of corruption on the marginal productivity of land clearing is ambiguous,

(7) $G_{Z\phi}(R, Z, \mathbf{w}, \mathbf{H}; \phi) = pF_{ZA}A_{\phi}$,

where F_{ZA} is the cross partial derivative of the production function. If F_{ZA} is positive (negative), land clearing and technology are complements (substitutes) because the marginal product of land clearing increases (decreases) as technology is developed. The development of new species of soybeans that adapt to tropical climate in Brazil and Bolivia is an example of a new technology that complements land use. On the other hand, development of new fertilizers is an example of a technology that substitutes land use.

Corruption control also has an effect on the cost of road building, $r(\phi)$. Corruption has been found to significantly increase the cost of infrastructure investment. Construction firms in Eastern Europe and Central Asia report paying an average of 7% of the value of government contracts in bribes to win an infrastructure project (Kenny 2006). Thus, raising corruption control can reduce the cost of road building such that $r_{\phi} \leq 0$.

We also introduce the effect of political stability on the provision of additional road networks in the rural sector as well as the cost of land clearing. Turnover could occur from coup attempts or votes of no confidence. If this occurs, infrastructure projects such as road networks are likely to be negatively affected (Gimenez and Sanau 2007). We assume that there is a probability, λ, where the current government is not overthrown and a peaceful transition of government occurs. If the government is overthrown, it is likely that current government projects will be stopped. Hence, we assume that the level of additional road building is zero when the current government is overthrown with probability $1-\lambda$.

Political stability could also affect the cost of land clearing, $c(\lambda)$. More stable governments are likely to continue and enforce policies that govern natural resource management. More political stability increases the cost of land clearing if the policies are stringent but the opposite holds if policies are lax. Thus, political stability may increase or decrease the cost of land clearing, i.e. $c_\lambda > 0$ or $c_\lambda < 0$.

The indirect social welfare function of the rest of the rural economy depends on macroeconomic variables as well as road networks, $\prod^R(R,\mathbf{H})$. More road networks are likely to increase welfare of the rest of the rural economy. Thus, we assume $\prod^R_R(R,\mathbf{H}) > 0$ and $\prod^R_{RR}(R,\mathbf{H}) < 0$.

To derive the effect of corruption control and political stability on land clearing and rural road building, we solve a two-stage problem. First, the representative landowner selects optimal amount of land clearing to maximize expected net returns from agricultural output given the available road networks. Next, the government maximizes expected social welfare by choosing the quantity of road networks to be built given the optimal amount of land cleared.

Demand for Agricultural Land

The representative producer maximizes expected returns from land net the cost of land clearing by choosing the amount of forest land to clear,

(8) $$\max_Z \Pi^P = \lambda G(R,Z,\mathbf{w},\mathbf{H};\phi) + (1-\lambda)G(0,Z,\mathbf{w},\mathbf{H};\phi) - c(\lambda)Z\ .$$

The returns from agricultural land expansion will depend on the ability of the government to create roads. When governments are politically stable, there is a probability of λ that the representative producer receives $G(R,Z,\mathbf{w},\mathbf{H};\phi)$. However, if the government is overthrown, infrastructure programs are likely to be stopped thus the representative producer gains $G(0,Z,\mathbf{w},\mathbf{H};\phi)$. The first order condition that maximizes the objective function is,

(9) $$\lambda G_Z(R,\bullet) + (1-\lambda)G_Z(0,\bullet) - c(\lambda) = 0\ .$$

Here, the expected marginal productivity of land is equated to the marginal cost of land clearing.

Solving for Z from (9) yields the demand equation for agricultural cropland,

(10) $Z = Z(R,\mathbf{w},\mathbf{H};\ \phi,\lambda)$.

The direct effect of corruption and political stability on agricultural land expansion is derived using the implicit function theorem on (9). We find the following,

$$(11) \qquad \frac{\partial Z}{\partial \phi} = -\frac{\lambda G_{Z\phi}(R,\bullet) + (1-\lambda) G_{Z\phi}(0,\bullet)}{\lambda G_{ZZ}(R,\bullet) + (1-\lambda) G_{ZZ}(0,\bullet)};$$

$$(12) \qquad \frac{\partial Z}{\partial \lambda} = -\frac{G_Z(R,\bullet) - G_Z(0,\bullet) - c_\lambda}{\lambda G_{ZZ}(R,\bullet) + (1-\lambda) G_{ZZ}(0,\bullet)}.$$

The denominator of (11) and (12) are negative to ensure a maximum. We find that the effect of corruption control on land clearing is ambiguous and will depend on the substitutability or complementarity of land and technology from (7). If land and technology are complements (substitutes), increased corruption control could lead to agricultural land extensification (intensification) thereby increasing (reducing) the amount of forested land cleared.

The effect of political stability on the amount of land cleared is also ambiguous because of the ambiguous effect of political stability on the cost of land clearing. If $c_\lambda > 0$, then more political stability leads to less land clearing; however, the results are ambiguous if $c_\lambda < 0$.

Government Provision of Rural Road Networks

The government optimally chooses the amount of additional road networks in the rural economy to maximize expected net returns from the agricultural sector along with expected welfare from other sectors in the rural economy given the cost of road infrastructure and the amount of land cleared. The government's problem is given by:

$$(13) \qquad \max_R \Pi^G = \lambda \Pi^R(R,\mathbf{H}) + (1-\lambda)\Pi^R(0,\mathbf{H}) + \Pi^P(R,Z,\mathbf{w},\mathbf{H};\phi,\lambda) - r(\phi)R,$$

Similar to the landowner's problem, there is a probability, 1-λ, where the road network project may not proceed. The first order condition that maximizes the government's welfare is,

(14) $\lambda(\Pi_R^R(R,\bullet)+G_R(R,\bullet))-r(\phi)=0$.

Here the expected marginal returns to the rural economy from road building are equal to the marginal cost of road building.

We derive a demand equation for road building from (14),

(15) $R = R\ (Z,\mathbf{w},\mathbf{H};\ \phi,\lambda)$.

The direct effect of corruption control and political stability on road building is derived using the implicit function theorem on (14),

(16) $$\frac{\partial R}{\partial \phi}=-\frac{\lambda G_{R\phi}(R,\bullet)-r_\phi}{\lambda(G_{RR}(R,\bullet)+\Pi_{RR}^R(R,\bullet))};$$

(17) $$\frac{\partial R}{\partial \lambda}=-\frac{G_R(R,\bullet)+\Pi_R^R(R,\bullet)}{\lambda(G_{RR}(R,\bullet)+\Pi_{RR}^R(R,\bullet))}.$$

The denominators of (16) and (17) are negative to ensure a maximum. More political stability increases road building only if the marginal returns of road building in the rest of the rural economy outweighs that of the agricultural sector, i.e. $G_R(R, \bullet) < \prod^R{}_R(R,\bullet)$. The effect of corruption control on road building is ambiguous. If corruption control has a smaller effect on reducing the cost of infrastructure compared to its effect on the marginal productivity of roads, then we expect that an increase in corruption control decreases road building.

Total Effect of Corruption Control and Political Stability

To derive the total effect of corruption and political stability on road networks and agricultural land expansion, we apply Cramer's Rule to (9) and (14),

(18) $$\frac{dZ}{d\lambda}=\frac{-\lambda(G_{RR}+\Pi_{RR}^R)(G_Z(R,\bullet)-G_Z(0,\bullet)-c_\lambda)+\lambda(G_R+\Pi_R^R)G_{RZ}}{\lambda^2G_{ZZ}(R,\bullet)(G_{RR}+\Pi_{RR}^R)+(1-\lambda)\lambda G_{ZZ}(0,\bullet)(G_{RR}+\Pi_{RR}^R)-\lambda^2G_{RZ}^2};$$

(19) $$\frac{dR}{d\lambda}=\frac{-(G_R+\Pi_R^R)\left(\lambda G_{ZZ}(R,\bullet)+(1-\lambda)G_{ZZ}(0,\bullet)\right)+\lambda G_{RZ}(G_Z(R,\bullet)-G_Z(0,\bullet)-c_\lambda)}{\lambda^2G_{ZZ}(R,\bullet)(G_{RR}+\Pi_{RR}^R)+(1-\lambda)\lambda G_{ZZ}(0,\bullet)(G_{RR}+\Pi_{RR}^R)-\lambda^2G_{RZ}^2}.$$

The denominators of (18) and (19) are positive to ensure a maximum. The primary factor determining the effect of political stability is the effect of political stability on the marginal cost of land clearing, c_λ. If $c_\lambda > 0$, an increase in political stability would decrease land clearing and increase road building in the rural economy. However, the total effect of political stability on road building and land clearing is ambiguous when $c_\lambda < 0$.

The effects of corruption control on Z and R are also ambiguous. Using Cramer's rule on (9) and (14) we find the following,

$$(20) \qquad \frac{dZ}{d\phi} = \frac{-(G_{RR} + \Pi_{RR}^{R})(\lambda G_{Z\phi}(R,\bullet) + (1-\lambda)G_{Z\phi}(0,\bullet)) + G_{RZ}(\lambda G_{R\phi} - r_\phi)}{\lambda G_{ZZ}(R,\bullet)(G_{RR} + \Pi_{RR}^{R}) + (1-\lambda)G_{ZZ}(0,\bullet)(G_{RR} + \Pi_{RR}^{R}) - \lambda G_{RZ}^{2}};$$

$$(21) \qquad \frac{dR}{d\phi} = \frac{-(\lambda G_{ZZ}(R,\bullet) + (1-\lambda)G_{ZZ}(0,\bullet))(\lambda G_{R\phi} - r_\phi) + \lambda G_{RZ}(\lambda G_{Z\phi}(R,\bullet) + (1-\lambda)G_{Z\phi}(0,\bullet))}{\lambda^{2} G_{ZZ}(R,\bullet)(G_{RR} + \Pi_{RR}^{R}) + (1-\lambda)\lambda G_{ZZ}(0,\bullet)(G_{RR} + \Pi_{RR}^{R}) - \lambda^{2} G_{RZ}^{2}}.$$

The denominators of (20) and (21) are positive to ensure a maximum. The substitutability or complementarity of land and technology in the agricultural sector and the marginal effect of corruption control on the cost of infrastructure determine the sign of the two comparative statics. More corruption control can lead to increased (decreased) land clearing and decreased (increased) road building when technology and land are complements (substitutes) and the effect of corruption control on the cost of infrastructure is low (high).

Empirical Model

We postulate that the vector **H** is composed of trade policies (T), foreign direct investment levels (F) and average economic income (I). Melitz (2003) shows that exposure to trade induces unproductive firms to exit the market, more productive firms to continue to produce in the domestic market and most productive firms to enter the export market. Foreign direct investment has also been shown to positively affect total factor productivity (Woo 2009).

Lastly, economic growth, especially urban growth, can also have a positive effect on productivity in the agricultural sector (Gardner 2005).

We also include a measure of domestically competitive output price in our land clearing equation. Output price in the rural sector is likely to depend on the competitive world price along with a price adjustment reflecting road network availability. We also include a measure of infrastructure cost in the road building equation.

We specify an empirical model to estimate the impact of governance on two direct factors of deforestation: road building and land clearing for cropland expansion. The empirical model specification is derived using equations (10) and (15) along with the above considerations,

$$\ln Z_{it} = \alpha_0 + \alpha_1 \ln R_{i,t-1} + \alpha_2 \ln Y_{it} + \alpha_3 \ln \overline{p}_{it} + \alpha_4 \ln F_{it} + \alpha_5 \ln T_{it} + \alpha_6 \ln \phi_{it} + \alpha_7 \ln \lambda_{it} + \vartheta_i + \zeta_t + \varepsilon_{it} \quad ; \tag{22}$$

$$\ln R_{it} = \beta_0 + \beta_1 \ln Z_{i,t-1} + \beta_2 \ln Y_{it} + \beta_3 \ln \overline{r}_{it} + \beta_4 \ln F_{it} + \beta_5 \ln T_{it} + \beta_6 \ln \phi_{it} + \beta_7 \ln \lambda_{it} + \delta_i + \chi_t + \eta_{it} \tag{23}$$

where subscript *i* and *t* represents country and time, respectively and α_j and β_j (j=0,..,7) are fixed parameters. Here, Z_{it} is area of forest land cleared for agricultural purposes in country *i* at year *t*; R_{it} is length of road networks the rural sector; Y_{it} is gross domestic product per capita; T_{it} is an index of trade policy openness; F_{it} is foreign direct investment; $\overline{p}_{it}$ is the crop price index of output from cleared land; $\overline{r}_{it}$ is the cost of road infrastructure; ϕ_{it} is a measure of corruption control; λ_{it} is a measure of political stability; ϑ_i and δ_i are country effects which can be fixed or random, ζ_t and χ_t are time effects common to all countries, and ε_{it} and η_{it} are disturbance.

Several important comments regarding the estimation of (22) and (23) are in order. International shocks that may be common to all countries in our sample may significantly affect road infrastructure project decisions as well as crop production. We account for this possibility by including time dummies for each year.

There may also be unobserved country characteristics such as weather, topography and land quality that affect the dependent variables. Exclusion of these variables could result in omitted variable bias. We include country fixed effects or random effects in our estimation. The underlying assumption in the Fixed Effects model allows endogeneity in all regressors and individual effects while in the Random Effects Model exogeneity is assumed. Alternatively, we relax the all or nothing choice of endogeneity with regressors by estimating a Hausman Taylor Random Effects (HTRE) model that assumes some of the regressors are correlated with the individual effects in the regressions.

Lastly, the impact of road networks on agricultural crop production into forested areas may not occur instantaneously. For this reason, road networks are lagged in the agricultural land expansion equation (22). Similarly, the expansion of agricultural crop production into forested areas may not immediately induce an increase in the rural road network. Thus, we also use lagged agricultural land expansion in the road networks equation (23). Given the lagged specification, autocorrelation may be present in both equations. We use the Huber-White estimate to calculate a robust standard error.

We calculate the short-run and long-run elasticities of forest cover from political stability and corruption control through the two direct factors of deforestation. The direct effects showing the short-run elasticities of corruption control and political stability on agricultural land expansion and road building are equal to α_6 and α_7, and β_6 and β_7, respectively.

In the long run, the effect of variables in time *t* are the same as in time *t-1*. To derive the long-run elasticities of corruption control on agricultural land expansion and rural road building, we totally differentiate (22) and (23) with respect to $\ln\varphi$, $\ln Z$ and $\ln R$,[3]

$$\begin{bmatrix} 1 & -\alpha_1 \\ -\beta_1 & 1 \end{bmatrix} \begin{bmatrix} \frac{d\ln Z}{d\ln\phi} & \frac{d\ln R}{d\ln\phi} \end{bmatrix}' = \begin{bmatrix} \alpha_6 \\ \beta_6 \end{bmatrix}.$$

A similar method is used to determine the long-run elasticity of political stability on the two direct factors of deforestation. The resulting long-run elasticities of corruption control and political stability on land clearing and road building in the rural sector are,

(24) $$\frac{d\ln Z}{d\ln\phi} = \frac{\alpha_6 + \alpha_1\beta_6}{1-\alpha_1\beta_1} \equiv \varepsilon_\phi^Z; \qquad \frac{d\ln R}{d\ln\phi} = \frac{\beta_6 + \alpha_6\beta_1}{1-\alpha_1\beta_1} \equiv \varepsilon_\phi^R;$$

(25) $$\frac{d\ln Z}{d\ln\lambda} = \frac{\alpha_7 + \alpha_1\beta_7}{1-\alpha_1\beta_1} \equiv \varepsilon_\lambda^Z; \qquad \frac{d\ln R}{d\ln\lambda} = \frac{\beta_7 + \alpha_7\beta_1}{1-\alpha_1\beta_1} \equiv \varepsilon_\lambda^R.$$

The above empirical methodology describes the calculation of short-run and long-run elasticities of governance indicators on the direct factors of deforestation, which constitutes estimation of Block 1 in our conceptual framework. We use estimates from existing microstudies that derive the elasticities of road building and land clearing on forest cover as shown in Block 2 of the framework. The total effect of governance on forest cover is derived by combining the results from Block 1 and Block 2. Thus, the short-run effects of corruption control and political liability on forest cover are,

(26) $$E_{F\phi}^S = \alpha_6\bar{\varepsilon}_Z^F + \beta_6\bar{\varepsilon}_R^F, \qquad E_{F\lambda}^S = \alpha_7\bar{\varepsilon}_Z^F + \beta_7\bar{\varepsilon}_R^F,$$

where $E^S_{F\varphi}$ is the total short-run elasticity of corruption control on forest cover, $E^S_{F\lambda}$ is the total short-run elasticity of political stability on forest cover, $\bar{\varepsilon}_Z^F$ is the short-run elasticity of agricultural land expansion on forest cover and $\bar{\varepsilon}_R^F$ is the short-run elasticity of rural roads on forest cover. We also derive the long-run effects of the measures of governance on forest cover,

(27) $$E_{F\phi}^L = \varepsilon_\phi^Z\varepsilon_Z^F + \varepsilon_\phi^R\varepsilon_R^F, \qquad E_{F\lambda}^L = \varepsilon_\lambda^Z\varepsilon_Z^F + \varepsilon_\lambda^R\varepsilon_R^F$$

where $E^{L}_{F\varphi}$ is the total long-run elasticity of corruption control on forest cover, $E^{L}_{F\lambda}$ is the total long-run elasticity of political stability on forest cover, ε_{Z}^{F} is the long-run elasticity of agricultural land expansion on forest cover and ε_{R}^{F} is the long-run elasticity of rural roads on forest cover.

III. DATA

We compile a unique cross-country dataset. Countries were selected based on the methodology of López et al. (2002) where developing countries with significant forest cover are identified based on the amount of absolute and relative forest land area. Furthermore, we focused only on those countries with agricultural crops that encroach on forest land, which narrows down our sample to countries in Latin America and Asia. There is evidence of tropical deforestation in Latin America due to slash and burn agriculture and pasture conversion practices (Houghton et al. 1991); and due to shifting cultivation in mountainous regions in Asia, especially in Southeast Asian countries (Rerkasem et al. 2009). African countries were excluded in the study because deforestation is mainly driven by the collection and consumption of fuelwood (Anderson and Fishwick 1984; Allen and Barnes 1985; Armitage and Schramm 1989; Cline-Cole et al. 1990; 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). There are twenty-two countries in our sample with data from 1990 to 2003. Appendix 1 lists these countries and identifies crops that encroach on forest land.

Table 1 shows the descriptive statistics from our sample. The key variables in our study are agricultural cropland encroaching on forest cover, crop price index, road and governance indicators. We calculated our own measure of cropland expansion by identifying crops encroaching on forested areas for each country in our sample. The selection of crops is based on available reports and studies about the country's food/cash crops and forest resources.[4] We add the total amount of harvested land area for each crop using data from FAOSTAT in each country. The creation of this unique and detailed variable allows us to obtain a more accurate estimate of the impact of agricultural land expansion on forest cover. If total agricultural land area is used, we could overestimate the effect of agricultural crop expansion on forest cover. We also calculate the crop price index from our selected crops using the Laspeyres index formula.

We used unpaved road length in kilometers from the World Development Indicators. It is a common type of infrastructure that connects agricultural land and forest land and precedes any paved road construction between the two areas.

The proxies for political stability and corruption control are government stability and corruption indices, respectively, which are obtained from the International Country Risk Guide published by the Political Risk Services Group. Government stability is composed of government unity, legislative strength and popular support. This indicator assesses the government's ability to implement its programs and to stay in office which captures the essence of our measure of political stability, λ. The total government stability rating ranges from 0 to 12 where a score of zero equates to low government stability. The second governance indicator is corruption within the political system, characterized by two main forms: 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. This proxy measure captures our corruption control index. The score of the corruption index ranges between 0 and 6, where zero denotes low corruption control. From our country sample, the political stability indicator scores between 3 and 11, and averages about 7.5 while the corruption control index has a score between 1 and 5 and an average of about 3.

Other variables used in our economic model are the gross domestic product per capita (GDP) in constant 2000 US$, foreign direct investment (FDI) as a percent of GDP, price of investment and trade openness index. Data for GDP and FDI were obtained from the World Development Indicators and investment price is from Penn World Tables. The trade openness index is derived from estimations by López et al. (2002) where they estimate a measure of trade policy openness instead of the usual trade volume measure. More (less) open countries have higher (lower) index values. Appendix 2 presents the definitions and data sources of all variables in the study.

IV. EMPIRICAL ESTIMATES

We present the regressions result relating the effects of governance on cropland expansion into forest areas and unpaved road development in the subsection below. Next, we combine the parameter estimates of our regressions with coefficients from other studies in the literature that measures the effect of direct factors of deforestation on forest cover.

Underlying Factors and Direct Factors of Deforestation

Tables 2 and 3 present the coefficient estimates of the determinants of two direct factors of deforestation: cropland expansion and unpaved road development based on (22) and (23). We calculated standard errors robust to heteroskedasticity and autocorrelation using the Huber-White estimator. The goodness-of-fit of the model is satisfactory as shown by the adjusted R-squared and significant coefficients across various estimation procedures.

Gross domestic product per capita has a consistently significant and large effect on unpaved road building and cropland expansion. We derive an elasticity of income per capita on cropland expansion ranging from 0.447 to 0.489 when controlling for country effects. The average growth rate of GDP per capita in our sample of countries is approximately 2.3%. Thus, given this growth rate, there is an increase in demand for agricultural land of about 1%. The elasticity of income per capita on unpaved roads is more elastic with values ranging from -1.198 to -1.683. The negative value indicates that unpaved roads may be inferior infrastructure goods relative to paved roads which are likely to be normal infrastructure goods. Given an average growth of GDP per capita equal to 2.3%, we find a decrease in unpaved road building of 2.7%.

The effect of lagged unpaved roads in the crop area regressions and the effect of lagged crop area expansion on unpaved road networks are both positive and significant. This result lends some support to our conceptual framework that road building and cropland expansion have a complementary relationship in the production of agricultural crops in the rural sector.

The effects of our governance variables on cropland expansion are significant and consistent across various specifications.[5] Corruption control has a consistent positive impact on crop area expansion with the exception of the OLS estimate which is likely to be biased. Our theoretical model explains this result. If corruption control induces technological development and if technological progress and land use are complements in the production of agricultural output, then corruption control could lead to agricultural extensification. On the other hand, we find a consistent negative and significant relationship between our political stability variable and crop area expansion, with the exception of our OLS estimates. Based on our theoretical model, this could be attributed to the rise in the cost of land clearing due to the creation and enforcement of policies protecting forest land. The sign of the governance variables are insignificant in the unpaved road regressions in all model specifications that control for country effects.

In order to calculate the total effect of our governance variables on forest cover, we select a benchmark model. We can use any of the estimates that allow for heterogeneous country characteristics as a benchmark. Here, we use the random effects estimates as benchmarks for the calculating the short-run and long-run effect of governance on forest cover since the Hausman test fails to reject the null hypothesis that the regressors are not correlated with the error term.

The short-run and long-run elasticities of governance are calculated using parameters from the random effects model. We use equations (24) and (25) to derive the long-run parameter estimates and we use the delta method to derive a measure of the standard errors. Table 4 summarizes the short-run and long-run elasticities of our measures of governance on two channels of deforestation: crop area expansion and unpaved roads. These results indicate that corruption control and political stability have a significant effect on crop area expansion but they are not significant on unpaved roads. The positive influence of corruption control on crop land expansion is similar to the results derived by Bulte et al. (2007). They find theoretically that governments prone to accept bribes in exchange for favorable policies (low corruption control) cause farmers to adopt inefficient modes of production (low technological quality). To the extent that low technological quality complements land use, then a decline in corruption control could lead to a reduction in crop area expansion. The negative effect of political stability on crop production is also consistent with the estimates from Lio and Hu (2009) where they find political stability leads to a reduction in agricultural efficiency. The long run and short run elasticities of corruption control and political stability are not statistically different from each other.

We also derive the long-run and short-run elasticities of GDP per capita and foreign direct investment on the direct factors of deforestation. GDP per capita has a significant positive effect on crop area but a negative effect on unpaved roads. The results are similar to López and Galinato (2005) for the crop area elasticity but the sign is different for roads. The differences in sign may be attributed to our use of unpaved road data, presumably an inferior good, while López and Galinato used paved road data, a normal good. Foreign direct investment has a negative effect on crop area expansion but positive effect on unpaved road construction which may indicate that investments are targeted towards non-agricultural activities. The short-run and long run effects of both variables are not statistically different from each other.

The Total Effect of Macroeconomic Variables on Forest Cover

We combine the parameters estimated from our regressions with coefficient estimates from other studies that utilize individual country survey statistics, remote sensing or GIS data to analyze the effect of direct factors on deforestation. We consider those micro studies that derived the long-run and short-run effects of forest competing crop area and roads. Given this set of micro studies, there are only a few studies that are most suited for our purposes based on location, methodological estimation, availability of descriptive statistics to compute implied standard errors and compatibility with our own parameter estimates.

In order to make our estimates more comparable with the parameter estimates of micro studies derived from different countries, we adjust the elasticity of the direct factors on forest cover. First, we use the implied marginal effects from the studies we selected. Then we calculate the elasticities of the direct factors on forest cover using the implied marginal effects along with the average forest cover, average unpaved road levels and average crop area in our sample.

The long-run and short-run effects of crop area on forest cover were taken from two studies. López (2000) estimated the effect of cultivation on forest clearing in rural villages in Western Ivory Coast. He shows that a one hectare increase in area cultivated results in 4.4 hectare decrease in forest cover. This marginal effect is larger than one because the conversion of forest cover to agricultural land also requires additional clearing for human settlement, infrastructure and other related activities supporting agricultural production. The implied marginal effect of crop area on forest cover in the Ivory Coast is remarkably similar to those derived by Osgood (1994) in Indonesia (4.25) and López (1997) in Ghana (3.9).[6]

We also use estimates from Maertens et al. (2006) to derive the long-run effect of shifting cultivation on forest cover. Their study focused on the long-run effect of shifting cultivation in Indonesia from 1980-2001. They arrive at an implied marginal effect of -0.88. The 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. Alternatively, some of the competing agricultural crops (rubber, palm oil and coconut) could also have been counted as secondary forest cover.

Panayotou and Sungsuwan (1994) measure the effect of road networks on forest cover in Thailand. They arrive at an implicit marginal effect -0.27 which means 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. However, we were able to find a study by McGuirk and Mundlak (1992) that estimated the long-run and short-run elasticities of the effect of roads on agricultural areas in India. They find that an increase in road networks by 1 kilometer increases agricultural land area by 0.0005 km^2 in the short run and 0.025 km^2 in the long run. If we assume that the new agricultural land that is created encroaches on forest cover, then we can derive the marginal effect of roads on forest cover by multiplying marginal agricultural land by the marginal crop area measure of forest cover from López (2000) of -4.4. The implied marginal effect of roads on forest cover is -0.002 km^2 in the short run and -0.11 in the long run. The larger long-run marginal effect of roads on forest cover can be attributed to the proliferation of other related human activity after the initial influx due to agricultural land expansion. Table 5 summarizes the elasticities of the direct factors affecting forest cover calculated from estimates in the micro studies. Given the non-linearity of the parameter estimates, we use the delta method to calculate the standard errors.

We use the elasticities derived from Table 4 and combine them with our elasticities in Table 5 to arrive at the total effect of governance, GDP per capita and foreign direct investment on forest cover using equations (26) and (27). Results are summarized in Table 6. The column labeled *Crop Area Channel* shows the net elasticity of our measures of governance on forest cover through the crop area channel only. There are two columns representing the effect of governance on forest cover through road networks. *Road Channel I* and *Total Effect I* uses the coefficient estimates from Panayotou and Sungsuwan for both the short-run and long-run estimates while the row labeled *Road Channel II* and *Total Effect II* uses estimates from McGuirk and Mundlak.

The elasticities of both our measures of governance on forest cover through the roads channel are consistently insignificant in both the short run and long run. In contrast, the effect of governance on forest cover through the cropland expansion channel is significant. Political stability decreases crop coverage which would result in an increase in forest cover in both the short run and long run with a larger statistically significant magnitude in the former. On the other hand, corruption control increases cropland expansion which leads to a decrease in forest cover in the short run and the long run with a statistically significant larger effect in the former. The total effect is dominated by the cropland expansion channel while the road channel is insignificant.

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 country with the highest measure of corruption control in our sample is Costa Rica. If the corruption control level of Brazil and Indonesia improved to the same stringency as Costa Rica, we estimate a 2% and 6% decrease in forest cover from agricultural land expansion in the short run, respectively. The most politically stable country in our sample is China. If Brazil and Indonesia improved government stability similar to the levels in China, we estimate an increase in forest cover by 2.3% and 1.6%, respectively, in the short run. There is also a consistent positive impact in the long run for the Brazil and Indonesia in the order of 0.4% and 0.2%, respectively.

Our empirical results showing a positive relationship between political stability and forest cover is also supported by Barbier (2004) but the negative relationship between corruption control and forest cover is contrary to the results of other models in the literature. Barbier (2004) and Bulte et al. (2007) use total agricultural land area from the FAO as proxies for cropland expansion and find that increased corruption control reduces agricultural land expansion. We can attribute the differences in empirical results to differences in the dependent variable. We refine our measure of cropland expansion to include only the agricultural land from crops that expand into forests and not all crop types. Thus, we may be obtaining a more precise estimate regarding the correlation between corruption control to cropland infringing on forest land only.

GDP per capita significantly affects forest cover through the cropland and road network channels. We find that the negative effect through the cropland channel is larger than the roads channel positive effect in the short run which leads to an overall decrease in forest cover as the economy grows. 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 0.17% and 0.34% in Latin America and Asia, respectively, in the short run. The actual rates of deforestation in Latin America and Asia are higher at an annual percentage change of 0.6% and

0.7%, respectively. Thus, income growth explains less than half of deforestation. The impact of other policies such as governance, trade and foreign direct investment may explain other sources of deforestation. In the long run, the positive effect of GDP per capita through road networks outweighs the negative effect through cropland resulting in an insignificant effect of economic growth. Thus, we do not find any persistent effect of GDP in the long run.

Foreign direct investment has a significant positive impact on forest cover in the short run because the positive effect through the cropland channel outweighs the negative effect through the road channel. This seems to indicate that investment is non-agricultural-oriented and could actually alleviate pressure on forest cover by allowing the urban sector to grow, thus putting less pressure on the rural sector. This particular result is different from López and Galinato (2005) wherein they find an insignificant effect of foreign direct investment on forest cover with the four countries in their sample. There is no significant effect of FDI on forest land in the long run.

V. CONCLUSION

This article investigated the effect of two governance indicators: corruption control and political stability on forest cover through agricultural expansion and road building. The main contributions of the article are: (1) the theoretical identification of the potential mechanisms by which the governance affects forest cover; and (2) the empirical structural measure of the effect of governance and other economy-wide variables on deforestation in the short run and long run. Using this approach as opposed to reduced form estimates allows us to identify the channels by which economy-wide variables affect forest cover.

The theoretical model shows the importance of the complementarity or substitutability of technology and land use in understanding how corruption control affects the agricultural land expansion choice. The primary factor determining the effect of political stability on agricultural land expansion is the effect of political stability on the marginal cost of land clearing.

We build a unique dataset to isolate agricultural land that encroaches on forest cover. The empirical results show that corruption control significantly decreases forest cover through the agricultural land expansion channel and the effect is larger in the short run than the long run. This particular result is counter to the results of other studies that estimate a reduced form model. There are two potential reasons why we achieve such diverging results. First, we construct our own measure of agricultural land by isolating only crops that we identify as forest encroaching instead of using aggregate agricultural land values. Second, we identify specific channels where corruption control affects forest cover. Similar to other studies in the literature, we also find that political stability has a positive and significant effect on forest cover because of a reduction in cropland encroachment. Unlike other studies, we are able to identify a lingering effect of political stability on forest cover in the long run.

We also find that GDP per capita has a strong negative effect on forest cover. The large negative effect is primarily due to the agricultural land expansion channel – an increase in income per capita leads to an increase in demand for cropland, thus, decreasing forest cover. This effect outweighs the positive effect through a reduction in road building. Although large, GDP per capita explains less than half of deforestation in our sample of countries. Other factors such as governance and other macroeconomic policies may also contribute significantly in explaining deforestation. Interestingly, unlike the governance indicators, GDP per capita does not have a lingering effect and is insignificant in the long run. Measures of governance may be an indication of an underlying structural infrastructure that has short-run and long-run effects while GDP per capita is only a short-run indicator.

The effects of foreign direct investment and trade are not as robust. López and Galinato (2005) found a robust negative effect of trade openness using four sample countries: Brazil, Indonesia, Malaysia and the Philippines. However, our estimates are insignificant over a larger sample of countries. This may indicate that not all countries, especially countries that are not necessarily agriculturally dependent, are likely to have forest covers sensitive to trade levels.

One limitation of this study is that the focus is only on deforestation caused by cropland expansion. A future study may examine the effects on deforestation through logging and rural poverty.

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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 IN DEVELOPING COUNTRIES, 1990-2003

Variables	OLS	TWFE	RE	HTRE
Lag of log unpaved roads	0.885 ***	0.131 ***	0.156 ***	0.136 ***
	(0.068)	(0.017)	(0.033)	(0.032)
Log of GDP per capita	1.145 ***	0.447 **	0.489 ***	0.469 ***
	(0.147)	(0.237)	(0.156)	(0.153)
Log of crop price index	0.237 ***	0.008	0.007	0.007
	(0.021)	(0.005)	(0.005)	(0.007)
Foreign direct investment over GDP	-0.153 ***	-0.008	-0.008 *	-0.008 *
	(0.064)	(0.007)	(0.005)	(0.005)
Corruption control	-0.935 ***	0.064 **	0.060 ***	0.063 ***
	(0.149)	(0.036)	(0.023)	(0.020)
Political stability	0.324 ***	-0.018 **	-0.017 ***	-0.018 ***
	(0.070)	(0.010)	(0.009)	(0.008)
Index of trade openness	0.020 ***	0.0003	0.0004	0.0003
	(0.003)	(0.001)	(0.001)	(0.001)
Constant	-4.949 ***	8.985 ***	8.501 *	8.375 ***
	(1.475)	(1.878)	(1.261)	(1.498)
R-squared	0.627	0.181	0.205	0.331
Number of observations	227	227	227	227
Annual dummies	Yes	Yes	Yes	Yes
Hausman test (prob Chi-squared)			(-)	(-)

Note: Robust standard errors.
*** 5%, **10%, *15%

TABLE 3

DETERMINANTS OF UNPAVED ROADS IN DEVELOPING COUNTRIES, 1990-2003

Variables	OLS	TWFE	RE	HTRE
Lag of log crop land	0.502 ***	0.694 *	0.582 ***	0.642 ***
	(0.042)	(0.463)	(0.138)	(0.104)
Log of GDP per capita	-0.776 ***	-1.683 **	-1.198 ***	-1.531 ***
	(0.144)	(0.937)	(0.337)	(0.273)
Log of investment price index	0.475	0.007	0.010	0.001
	(0.458)	(0.150)	(0.095)	(0.124)
Foreign direct investment over GDP	-0.052 *	0.026 ***	0.027 ***	0.026 ***
	(0.035)	(0.010)	(0.009)	(0.010)
Corruption control	0.333 ***	-0.017	-0.013	-0.014
	(0.096)	(0.051)	(0.038)	(0.037)
Political stability	-0.070	0.018	0.011	0.016
	(0.057)	(0.019)	(0.013)	(0.015)
Index of trade openness	-0.011 ***	-0.001	-0.001	-0.001
	(0.002)	(0.001)	(0.001)	(0.002)
Constant	7.139 ***	13.598 ***	11.572 ***	12.374 ***
	(1.415)	(3.904)	(2.009)	(2.177)
R-squared	0.497	0.362	0.382	0.399
Number of observations	251	251	251	251
Annual dummies	Yes	Yes	Yes	Yes
Hausman test (prob Chi-square)			0.997	1.000

Note: Robust standard errors.
*** 5%, **10%, *15%

TABLE 4.
SHORT-RUN VERSUS LONG-RUN ELASTICITY OF GOVERNANCE ON THE DIRECT FACTORS OF DEFORESTATION

	Elasticity on Crop Area	Elasticity on Unpaved Roads
Short run[1]		
Corruption control	0.174***	-0.038
	(0.068)	(0.111)
Political stability	-0.131***	0.082
	(0.064)	(0.096)
GDP per capita	0.489***	-1.198***
	(0.156)	(0.337)
Foreign direct investment	-0.021*	0.070***
	(0.014)	(0.025)
Long run[2]		
Corruption control	0.185***	0.070
	(0.077)	(0.132)
Political stability	-0.130***	0.006
	(0.072)	(0.116)
GDP per capita	0.332***	-1.005***
	(0.181)	(0.385)
Foreign direct investment	-0.011	0.064***
	(0.017)	(0.029)

[1] Short-run elasticities are derived using parameters from the random effects models. The coefficients in Tables 1 and 2 reflect the percentage change of the direct factor of deforestation given a unit change in the governance variable. In order to convert this to the appropriate elasticity measure, we use the formula αX where α is the parameter estimate and X is the mean value of the governance indicator. The standard error is equal to s(α)X where s(α) is the standard error of the parameter.

[2] Long-run elasticities are calculated using parameters from the random effects models in Tables 1 and 2 using equations (24) and (25). Asymptotically, the variance of a nonlinear univariate function, *g(A)*, is equal to $V(g(A)) = \left(\partial g / \partial A\right)^T V(A) \left(\partial g / \partial A\right)$ where $\partial g/\partial A$ is a vector whose i^{th} element is the partial derivative of *g* with respect to the i^{th} element *A,* and *V(A)* is the variance-covariance matrix of the parameters in the vector *A*.

TABLE 5

IMPLIED DIRECT EFFECT ELASTICITIES ON FOREST COVER FROM MICRO STUDIES

Direct Effects	Short-run elasticities	Long-run elasticities
Crop elasticity on forest	-0.267***	-0.053***
cover (ε_Z^F)[1]	(0.017)	(0.009)
Road elasticity on forest	-0.022**	
cover I (ε_R^F)[2]	(0.016)	
Road elasticity on forest	-0.00018***	-0.009*
cover II (ε_R^F)[3]	(0.00001)	(0.008)

*** 5%, **10%, *15%

[1] The short-run elasticity is derived by multiplying the marginal effect from López (2000) of -4.4 by the ratio of crop area to forest cover from the sample in the data (41,478/683,676). The long-run elasticity is derived by multiplying the marginal effect from Maertens et al. (2006) of -0.88 by the same ratio.

[2] The short-run elasticity is derived by multiplying the marginal effect from Panayotou and Sungsuwan (1994) of -0.27 by the ratio of road density to forest cover from the sample of countries in the data (56,790/683,676).

[3] The short-run elasticity is derived by multiplying the marginal effect of agricultural land from McGuirk and Mundlak (1992) of 0.000514 with López's estimate of -4.4 and the ratio of road density to forest cover from the sample of countries in the data (56,790/683,676). The long-run elasticity is measured in a similar manner but a marginal effect of agricultural land equal from McGuirk and Mundlak (1992) of 0.0258585 is used.

TABLE 6

SHORT-RUN VERSUS LONG-RUN ELASTICITY OF GOVERNANCE ON FOREST COVER

	Cropland Channel	Road Channel I[1]	Road Channel II[2]	Total Effect I[1]	Total Effect II[2]
Short run[1]					
Corruption control	-0.047***	0.001	0.00001	-0.046***	-0.047***
	(0.018)	(0.003)	(0.00002)	(0.019)	(0.018)
Political stability	0.035***	-0.002	-0.0002	0.033***	0.035***
	(0.017)	(0.002)	(0.00001)	(0.017)	(0.017)
GDP per capita	-0.130***	0.026**	0.0002***	-0.104***	-0.130***
	(0.043)	(0.020)	(0.0001)	(0.047)	(0.043)
Foreign direct	0.006**	-0.002*	-0.00001***	0.004	0.006**
investment	(0.004)	(0.001)	(0.000005)	(0.004)	(0.004)
Long run[2]					
Corruption control	-0.010***	-0.002	-0.001	-0.011***	-0.011
	(0.004)	(0.003)	(0.014)	(0.005)	(0.014)
Political stability	0.007***	-0.0001	-0.0001	0.007**	0.007**
	(0.004)	(0.003)	(0.002)	(0.005)	(0.004)
GDP per capita	-0.018***	0.022*	0.009	0.005	-0.008
	(0.010)	(0.018)	(0.195)	(0.021)	(0.195)
Foreign direct	0.001	-0.001*	-0.001	-0.001	0.000004
investment	(0.001)	(0.001)	(0.012)	(0.001)	(0.012)

*** 5%, **10%, *15%

[1] Coefficient estimates from Panayotou and Sungsuwan (1994) are used.

[2] Coefficient estimates from McGuirk and Mundlak (1992) are used.

Figures

FIGURE 1
LINKING DEFORESTATION TO GOVERNANCE

FIGURE 2
COUNTRY DOMINANCE CHECK IN CROP LAND RANDOM EFFECTS MODEL

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
Honduras	Beans, coffee, maize	Tucker, C.M., D.K. Munroe, H. Nagendra and J. Southworth. 2005.

Country	Crop/s	Source/s
		"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.
Pakistan	Sugar cane	Abbas, M. , S.H. Khan, R.A. Khan and M. Shahbaz. 2004. "Impact of Wild

Country	Crop/s	Source/s
		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. Given space limitations, we do not include here the citations from each individual study that helped us identify these crops. The citations are available from the authors on request.

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 orruption 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.

[1] One important direct factor is logging. The fact that initial logging is usually followed by agricultural production especially in developing countries makes it difficult to separate the effect of logging and agricultural expansion. Our analysis of agricultural land expansion refers only to crop production and not livestock production because the mechanisms by which governance affects deforestation may differ between the two production technologies.

[2] From this point forward, our notation for the derivative and second derivative of function F(x) with respect to x is $\partial F/\partial x \equiv F_x$ and $\partial^2 F/\partial x^2 \equiv F_{xx}$.

[3] To avoid notation clutter, we drop the *i* and *t* subscripts since $t=t-1$ for all *t*.

[4] Due to space limitations, we do not include the full reference list for Appendix 1. The list of sources identifying crops in each country is available from the authors upon request.

[5] To test for any effect of country outliers, we dropped country observations one at a time and checked whether the sign of coefficient estimates for corruption control and political stability changed in the cropland area random effects regression. There is no significant change in the coefficients for either parameter as shown in Figure 2.

[6] It was difficult to accurately calculate the standard errors from these two studies therefore we opted to use the coefficient estimates from the Ivory Coast.