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# An empirical analysis of the cumulative nature of deforestation

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Deforestation is one of the major environmental issues in developing countries and agricultural expansion is its first cause. Using the Forest Transition hypothesis, the aim of this paper is to improve the knowledge of the cumulative nature of deforestation. To do this, the macroeconomic factors which promote the end of the deforestation in a given country are highlighted. Then, the total amount of deforestation during the development is explained.

*Keywords*: forest transition; cumulative deforestation; land-use; switching model; seemingly unrelated regression

*JEL codes*: C21, O13, Q33

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# An empirical analysis of the cumulative nature of deforestation

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**Abstract**

Deforestation is one of the major environmental issues in developing countries today, and agricultural land expansion is one of its main causes. The objective of this paper is twofold: (1) to identify the macroeconomic determinants of the end of deforestation; and (2) to explain cumulative deforestation together with its associated economic development. To do this, we first studied the occurrence of a turning point (i.e., the change from decreasing to expanding forest areas) and, second, adapted a land-use model to explain the trade-off between forest and agriculture at the turning point, using the Forest Transition (FT) theory. To take the link between both phenomena into account, we estimated a switching seemingly unrelated regression (SUR) model, applied to a panel dataset of 68 developing countries. The estimation results reveal that economic development and institutions play a significant role in long-term deforestation. We also found evidence of leakage effects. Finally, our results suggest that after the first development stage, agriculture and forest are not always competing land uses.

*Keywords*: Forest transition; cumulative deforestation; land use; switching seemingly unrelated regression model

*JEL codes*: C21, O13, Q33

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# 1 Introduction

Deforestation is an important factor of global climate change. It is also one of the major environmental issues in developing countries because it generates desertification and soil erosion and threatens biodiversity. In this context, major improvements in the global understanding of deforestation are still required. So far, the empirical literature on the topic (e.g., Arcand et al. (2008); Combes-Motel et al. (2009); Culas (2007); Damette and Delacote (2011, 2012); Nguyen-Van and Azomahou (2007); Scriecu (2007)) has provided useful results but has focused on factors that account for periodic deforestation rates (annual deforestation rates or five-year rates). However, it is important to understand the role of deforestation patterns on the whole development path, and not only periodic ones.

The Forest Transition (FT) theory is a useful tool to improve this understanding. This theory, introduced by Mather (1992), refers to *"the change from decreasing to expanding forest areas that has taken place in many developed countries"*. The point at which the forest cover stops decreasing in the country is called the turning point. It is of particular interest as it makes it possible to consider the cumulative deforestation of a nation all along its development path. It also provides structural information about the entire deforestation stage. As a consequence, explaining when and why the turning point occurs helps us to understand which macroeconomic factors lead to the end of deforestation.

In developing countries, land-use competition occurs mainly between agriculture and forest, and agricultural land expansion represents the major direct cause of deforestation[1]. Gibbs et al. (2010) reported that between 1980-2000, across the tropics, "*more than 55% of new agricultural land came at the expense of intact forests, and another 28% came from disturbed forests*". Hence, a better understanding of the cumulative nature of deforestation makes it necessary to highlight the determinants of land allocation - agriculture or forest - on the long term.

Using the FT theory, this paper thus makes two major contributions. First, we studied the occurrence of a turning point. To do this, we estimated the probability for a developing country to experience a turning point over the period 1985-2005. The objective was to highlight the factors that lead to the end of deforestation in a given developing country. Second, we used a land-use model to improve our knowledge of the cumulative nature of deforestation. Focusing on the determinants of the different land uses at the turning point, we provided information about the total deforestation and agricultural land expansion during development. This approach provides new evidence to better understand why some turning points occur at a relatively high level of forest area or, on the contrary, once whole forests have been cut down in the country[2]. As an interesting complement, we also attempted to determine the determinants of land uses for developing countries that are still undergoing deforestation. Indeed, we observed each of the developing countries in our sample when it belonged to one of two regimes (i.e., before or after deforestation). It is hoped that our results will help design public policies so that future turning points will occur earlier while greater forest areas still remain.

Although the occurrence of a turning point and the level of deforestation are two different issues, it is highly likely that they are correlated. Indeed, we may expect the end of deforestation to be related to a low level of forest cover. More generally, the determinants of land use are likely to be different in both regimes. Moreover, several factors

[1]Expanding agriculture may also cause indirect land-use changes. These occur when agricultural activities shifted from one region lead to the expansion of the same land use in another region (Andrade de Sá et al., 2013)

[2]In France, for example, the turning point occurred when forest areas represented 14% of the total land, whereas in Ireland, it occurred when the forest cover had fallen to 2% of the total land.

simultaneously explain the occurrence of a turning point (and the trade-off between different land uses, mainly forest cover, agriculture and urban area) and the distribution of land uses. Some factors can be observed (e.g., agricultural prices) whereas, for some others, direct observation is more difficult (when related to public (country) preferences, for example). A further contribution of this paper is thus methodological. We used a switching seemingly unrelated regression (SUR) model, which consists of two steps: (1) estimating a probit model that explains the occurrence of a turning point; and (2) estimating a system of land-use shares for two different regimes: $FT = 1$ when the developing country has experienced a turning point, and $FT = 0$ when the developing country is still undergoing deforestation. Our model was applied to a panel dataset of 68 developing countries.

The next section presents the FT hypothesis. Section 3 focuses on the interest of studying turning points and their related land-use shares. Data and econometric methodology are described in Section 4. Section 5 presents the results, and Section 6 is devoted to a discussion.

## 2 The forest transition hypothesis: a long-term analysis of land use in developing countries

During the early development phase, the main land-use trade-off pits agriculture and forest against each other. In response to economic incentives, choices for land use are made at the microeconomic scale. When aggregated, they form a macroeconomic trend that can be viewed as the land use/cover change (LUCC) of a given country. For several decades now, researchers have taken an increasing interest in the LUCC in order to better predict the impact of local actions on global climate change (Lambin et al., 2003). The FT hypothesis is a component of the LUCC framework since it allows a better understanding of the evolution of the forest area of a country and, as a result, the consequences in terms of climate or ecology. Following the FT hypothesis, the forest cover varies under different phases: deforestation, stagnation and reforestation (see Fig. 1).

[ Fig. 1 here ]

The major phase of deforestation is composed of two stages. First, new accesses to forests are created, both for state control and rent access (mining, logging, etc.). This boosts agricultural rents by providing new markets that lead to a population shift towards the area. The global rate of forest losses remains low, considered as the *pre-development* phase. Second, the growth of the local population implies a strong demand for food and space and ensures the supply of labor at low wages. This population effect is combined with the development of processing activities such as dairies or slaughterhouses. Agricultural rents are relatively high and production expands. The clearing process is reinforced (Angelsen, 2007) and the deforestation rate is high. This is the major phase of deforestation that provides income and capital, and makes it possible to satisfy food and energy needs.

Following the deforestation phase, a phase of stagnation occurs as agricultural rents decrease and forest rents increase, determining the *turning point* of the forest transition. This corresponds to a reversal in the deforestation rate: the gross variation of the forest cover turns sustainably from negative to positive or null. Grainger (1995) highlights that the period of stagnation may last decades or even centuries, like in the case of England.

One way to explain the occurrence of the turning point comes from the *economic development* pathway, proposed by Rudel et al. (2005). Once a certain level of income per capita and of capital stock is reached, the country is able to switch from an agriculture-based economy into an industry-based economy. Farmers leave their lands for urban jobs with higher wages. Agricultural production becomes more intensive and some previously abandoned lands revert to forest. The development path is consistent with the Environmental Kuznets Curve (EKC) hypothesis, where deforestation and income are related by an inverted U-shaped relationship. Several empirical studies on deforestation have tested this relationship (Culas, 2012), finding contradictory results (Choumert et al., 2012). However, the development path (1) is specifically related to forests, whereas the EKC concerns any type of environmental indicator, and (2) considers economic development through sectorial switches (from extensive agriculture to intensive agriculture, industrialization and urbanization), whereas the EKC focuses on income.

The turning point can also be explained by the *forest scarcity* pathway (Rudel et al., 2005), which relies on the rise of forest rents and refers to the comparison of land-use marginal values. At the beginning of the development phase, a country has a relatively extensive forest cover and few agricultural lands. Hence, the marginal value of agriculture is high as it can provide many benefits to the population. In contrast, the marginal value attributed to forests is low in the sense that forests are abundant and thus less marginally valued. As long as forests are converted to agriculture, the marginal value of forests increases (as forests become scarcer) and the value of agricultural land decreases (since newly converted land is less and less productive), until a point at which both marginal values equalize, defining the turning point (Barbier et al., 2010). This scarcity leads to higher prices for forest products and thus involves plantation. Moreover, the potential environmental issues induced by the lack of forests, such as floods in China, boost the marginal value of forests and favor plantation.

Besides, globalization may also lead to the end of net deforestation (i.e., to experiencing a turning point) as a result of neo-liberal reforms, labor out-migrations and the development of tourism (Lambin and Meyfroidt, 2010). In some countries, global trade has led to the adoption of more protective environmental policies and, thus, to transitions. In addition, some specific government policies may lead to a FT, as was the case in Bhutan, which experienced an especially early turning point due to the fact that the government prohibits a total land area under forest of below 60% of the total area.

Finally, the stagnation phase may be followed by reforestation, mainly by plantation. The growth of the secondary forest occurs as nations become aware of the ecological benefits provided by forests and seek to take advantage of forest rents as well. Improving the understanding of the cumulative nature of deforestation requires a better understanding of the land allocation over the long term. To do this, the following section focuses on the interest of studying the turning point and then presents the 15 developing countries that have experienced such a turning point.

# 3 Analyzing cumulative deforestation

## 3.1 Considering deforestation issues on the basis of the turning point

At the turning point, marginal values of both agriculture and forest are assumed to be equal (Barbier et al., 2010). The first one is decreasing, while the second one is increasing. At this point, the economy is shifting from agriculture to industry. More off-farm jobs are available and urbanization takes place. The nation has collected enough capital to invest in new sectors such as agricultural intensification and industry (Rudel et al., 2005).

This FT approach makes it possible to analyze a country's deforestation throughout the entire development phase, whereas most studies consider deforestation rates over yearly periods (Arcand et al., 2008; Combes-Motel et al., 2009; Culas, 2007; Damette and Delacote, 2011, 2012; Nguyen-Van and Azomahou, 2007; Scriecu, 2007). Thus, our approach avoids periodic determinants of deforestation and focuses on structural ones, providing a different and valuable point of view of the phenomenon. Two examples illustrate this, with different periodic influences on the deforestation rate. In 1994, the CFA (Central African Franc) was devaluated by 50%. The demand for wood products in the CFA franc area consequently increased, implying the growth of the deforestation rate over this period. Another example of periodic influence on the deforestation rate is the economic crisis of 2008, which slowed the demand for timber products and then reduced the pressure on remaining forests (FAO, 2009). These two examples show how deforestation may increase or decrease due to periodic effects.

In contrast, at the turning point, cumulative information on deforestation is available since we consider the entire first stage of FT. Why do some countries experience a turning point at 10% forest cover while others experience it at 30%? Focusing on the forest cover at a point in time implies identifying the variables that influence this level and explain the total forest loss. In the end, explaining the turning point corresponds to explaining how deforestation ends in a given country, thus improving the global understanding of the cumulative nature of deforestation.

Since deforestation results in a trade-off between agriculture and forest, it is useful to analyze agricultural expansion throughout the development phase. Indeed, identifying the macroeconomic variables that explain the total agricultural area at the turning point can help to preserve more forests before the turning point. Results may thus provide insights for countries that have not yet experienced a turning point, in order to help those countries to end deforestation earlier while maintaining a greater forest cover.

## 3.2 Developing countries that have experienced a turning point in their forest cover

In this section, the way in which countries are considered or not to have experienced a turning point is presented. A country is considered to have undergone a turning point when a non-monotonic evolution of the forest cover with a global minimum over the 1985-2005 period is observed.

In our sample, 15 countries experienced such an evolution. Obviously, the turning point that was observed may not be permanent and the selected countries may experience deforestation in the future. Nevertheless, our analysis considers observations in which deforestation ceases, either temporarily or permanently. In Appendix D, we present the case of Vietnam, which appears to have experienced a turning point in its forest cover between 1985-1990.

In order to strengthen our empirical observations about a potential turnaround, we checked the validity of the 15-country sub-sample. To do this, we based our observations on four main research papers on FT (Mather, 1992; Meyfroidt et al., 2010a,b; Rudel et al., 2005). We also used observations reported in several international reports provided by the FAO. Table 1 sums up papers where a given country has been cited as observing a FT. These cross-references consolidate our time-series observations and confirm the existence of a turning point in forest covers in those 15 countries.

[ Table 1 here ]

# 4 Land use and cumulative deforestation in developing countries

In this section, we first describe the economic framework of our paper. We then present the econometric model, followed by the data that we used to establish it.

## 4.1 Economic framework

The aim of our model is to illustrate the land allocation throughout the development process. Hence, as in the case of Barbier et al. (2010), we studied land use, focusing on forest vs. agriculture. The model we used in this study is similar to classical models of land distribution. We just adapted the conceptual basis of farmer behavior based on profit maximization for the allocation of different crop lands, to the benefits that a developing economy derives from the distribution of land uses.

Consider a country that has thousands of hectares ($LC_j$) of land type $j$ ($j = 1, ...., J$). The total surface area of the country is then $TC = \sum_j LC_j$. We assume that a developing country's representative agent allocates the total surface area across different land uses and chooses the amount of land for each type $j$. This land allocation depends, among other things (such as the unobserved land marginal productivity), on exogenous variables $X_j$, including macroeconomic variables (e.g., population, income, agricultural yields). We acknowledge the fact that assuming a representative agent may not reflect the very large variety of deforestation agents in developing countries (rural households, firms, etc.). Moreover, macroeconomic variables may not have the same impact on this very diverse set of actors in relation to their land-use choice. Nevertheless, relying on such a representative agent framework aims at aggregating the diversity of those agents in order to allow the macroeconomic variables that most affect the land-use choices at the level of the country to emerge.

Let $B_j(X_j)$ designate the net benefits derived from land type $j$. The land allocation can therefore be established in order to maximize total net benefits for each land type:

$$\max_{LC_j} \sum_j B_j(LC_j, X_j) \tag{1}$$

subject to

$$TC = \sum_j LC_j \tag{2}$$

The solution of this problem gives the optimal land allocation for land type $j$:

$$LC_j^*(X_j) \tag{3}$$

Equation (3) can be written in share form as:

$$S_j^* = \frac{LC_j^*}{TC} \equiv S_j^*(X_j) \tag{4}$$

Equation (4) represents the equilibrium land use and, thus, the turning point patterns that may depend on macroeconomic variables that we present in the following section.

## 4.2 A two-step model estimation

For the empirical application, we assume that the share equations take a logistic form. Three main types of land uses are defined: forest, agriculture and, to a lesser extent, urbanization. The latter represents a low percentage of the total land area compared to the two former ones. Hence, the share of land use $j$ in country $i$ is:

$$S^*_{ij} = \frac{exp(f_j(X_j))}{\sum_{j=0,A,F} exp(f_j(X_j))}, \quad j = 0, F, A \tag{5}$$

where a reference category ($j = 0$) is defined, namely the surface area not devoted to forest ($j = F$) or to agriculture ($j = A$). The summation in equation (5) is over all land uses. Applying commonly used mathematical formulas, it is possible to eliminate this reference category. Indeed, since the three land uses are complementary, we can focus on only two land uses, the third one being implicitly explained by the results on the two former ones. We thus have[3]:

$$S^*_{ij} = \frac{exp(f_j(X_j))}{1 + \sum_{j=A,F} exp(f_j(X_j))}, \quad j = F, A \tag{6}$$

We estimate the share of both forest and agricultural areas at the turning point (if any). Since agriculture expands at the expense of forests, we may expect individual correlations between errors of those two equations. Therefore, we use Zellner's seemingly unrelated regression (SUR) model. To identify the factors that influence the forest transition, a standard probit model was chosen:

$$\begin{aligned} FT^*_i &= W_i\beta + \epsilon_{FTi} \\ FT &= 1 \text{ if } FT^*_i > 0 \\ FT &= 0 \text{ if } FT^*_i \leq 0 \end{aligned} \tag{7}$$

where $FT^*_i$ is an (unobservable) latent variable, $W_i$ is a vector of exogenous variables, $\beta$ is the associated vector of parameters, and $FT$ is a binary variable indicating the observation of a turning point when $FT = 1$. The normalization restriction is assumed: $\epsilon_{FTi}$ is an error term with 0 mean and variance equal to 1.

Shares of land use depend on whether the country is undergoing deforestation or not. We can thus distinguish whether countries are experiencing a turning point or not. More specifically, we can expect variables that significantly affect the forest cover at the turning point to explain cumulative deforestation, which is not the case for variables that explain the forest cover in a deforestation regime. Since the share of land use is linked to the forest transition of the country, estimating share equations separately from this switching process may result in a selection bias. This is why we estimate the SUR model by integrating first-stage results of the probit equation.

Hence, we estimate two systems of SUR, depending on whether the country has experienced a turning point or not:

$$Y_{FT=1} : \begin{cases} S_{iF1} = X_{i1}\beta_{F1} + \epsilon_{iF1} \\ S_{iA1} = X_{i1}\beta_{A1} + \epsilon_{iA1} \end{cases} \tag{8}$$

$$Y_{FT=0} : \begin{cases} S_{iF0} = X_{i0}\beta_{F0} + \epsilon_{iF0} \\ S_{iA0} = X_{i0}\beta_{A0} + \epsilon_{iA0} \end{cases} \tag{9}$$

where $\epsilon_{iF1}$, $\epsilon_{iA1}$, $\epsilon_{iF0}$ and $\epsilon_{iA0}$ are the random disturbances with zero means and constant but different variances.

Hence, two cases occur: (1) The country observes a turning point in its forest cover ($Y_{FT=1}$) and we estimate shares of land use at this point in time; (2) The country is still undergoing deforestation ($Y_{FT=0}$). Explaining land use during this phase means explaining both deforestation and agricultural expansion. The different shares of land use therefore have different meanings, depending on the country's regime. As a consequence, our model has to take this information into account since it introduces a correlation between the error terms of each system and the error

[3] In the same way, we can deduce that: $S^*_{i0} = \frac{1}{1+\sum_{j=A,F} exp(f_j(X_j))}$.

term of selection equation $\epsilon_{FTi}$. It follows that:

$$\begin{aligned}
E(\epsilon_{iF1}|FT_i^* > 0) &= \rho_{F1}\tfrac{\phi(\psi)}{\Phi(\psi)} \\
E(\epsilon_{iA1}|FT_i^* > 0) &= \rho_{A1}\tfrac{\phi(\psi)}{\Phi(\psi)} \\
E(\epsilon_{iF0}|FT_i^* \leq 0) &= -\rho_{F0}\tfrac{\phi(\psi)}{1-\Phi(\psi)} \\
E(\epsilon_{iA0}|FT_i^* \leq 0) &= -\rho_{A0}\tfrac{\phi(\psi)}{1-\Phi(\psi)}
\end{aligned} \tag{10}$$

where $\frac{\phi(\psi)}{\Phi(\psi)}$ and $-\frac{\phi(\psi)}{1-\Phi(\psi)}$ are the inverse Mill's ratio for the probit model, with $\psi = W_i\beta$ and $\rho_{F0}$, $\rho_{A0}$, $\rho_{F1}$ and $\rho_{A1}$ the parameters to be estimated. $\phi$ and $\Phi$ are the density and distribution functions, respectively, of the standard normal. Consequently, in that case, both ordinary and generalized least square estimations of systems (8) and (9) yield inconsistent estimates. To correct this, we use the above results to adjust the conditional mean error term to zero.

This results in a two-step estimation procedure. First, the (probit) selection mechanism is estimated by using a maximum likelihood estimation (MLE) in order to obtain estimates of $\beta$ and to compute the inverse Mill's ratio. Second, we estimate the following two systems of (seemingly unrelated) regressions:

$$Y_{FT=1}: \begin{cases} S_{iF1} = X_{i1}\beta_{F1} + \rho_{F1}\frac{\phi(\psi)}{\Phi(\psi)} + \nu_{iF1} \\ S_{iA1} = X_{i1}\beta_{A1} + \rho_{A1}\frac{\phi(\psi)}{\Phi(\psi)} + \nu_{iA1} \end{cases} \tag{11}$$

$$Y_{FT=0}: \begin{cases} S_{iF0} = X_{i0}\beta_{F0} - \rho_{F0}\frac{\phi(\psi)}{1-\Phi(\psi)} + \nu_{iF0} \\ S_{iA0} = X_{i0}\beta_{A0} - \rho_{A0}\frac{\phi(\psi)}{1-\Phi(\psi)} + \nu_{iA0} \end{cases} \tag{12}$$

Both systems of equations are thus adjusted with a Heckman-type correction term.

The estimation of the switching model typically proceeds in two steps: first, parameters $\beta$ of equation (1) are consistently estimated by a probit for each period (1990, 2000 and 2005), and the inverse Mill's ratio is then saved. In a second step, we estimate the SUR models (11) and (12) (that include the inverse Mill's ratio) by a procedure adapted to panel data, which we describe below.

## 4.3 Data description

We carried out our analysis on a panel dataset of 68 developing countries listed in Appendix A. Each country was observed over three years: 1990, 2000, 2005. We used these three years because they were non-extrapolated points provided by the FAO, and could therefore be expected to provide a higher degree of reliability. Details on both explained and explanatory variables are given below. In addition, data sources are given in Appendix B, and descriptive statistics for different samples are provided in Appendix C.

### 4.3.1 Dependent variables

#### Turning point variable

In the first step of our study, we attempt to explain the occurrence of a turning point. We use a dummy variable as the dependent variable in the probit model, taking the value of 1 if the country has experienced a turning point over the period 1985-2005 (FT=1), and 0 otherwise (FT=0).

#### Land-use share variables

Land-use share equations (i.e., forest and agricultural shares) are estimated at the turning point (when FT=1) and during the deforestation phase (when FT=0). On the basis of equation (6), we can write:

$$\ln\left(\frac{S^*_{ij}}{S^*_{i0}}\right) = f_j(X_j), \quad j = F, A \tag{13}$$

where $f_j$ is a linear function. Hence, the dependent variables of the second step of the model (i.e., the relative shares of forest and agriculture) are expressed as $ln(S^*_F/S^*_0)$ and $ln(S^*_A/S^*_0)$, respectively.

### 4.3.2 Control variables

Our set of control variables is related to the transition paths and the usual determinants of deforestation. Economic development and forest scarcity pathways, population pressure, the influence of institutions, agricultural rents and global trade are then taken into account in order to analyze the cumulative nature of deforestation.

#### Economic development path

One way to explain the FT is the economic development path (Rudel et al., 2005). Once it is sufficiently developed, a given country may switch towards other activities such as industry. We use GDP per capita and its growth rate as variables that are expected to hasten the turning point. Over the long run, development contributes to forest preservation and limits cumulative deforestation. This idea is directly related to the forest's EKC. Moreover, economic development may lead to intensive production and lower agricultural area at the turning point.

#### Forest scarcity path

In the second section, we highlighted how forest scarcity leads to the increase in forest rents. Both the price of forest products and the marginal value of forest finally increase with forest depletion, due to agricultural land expansion. With the increase wages and the decrease of labor supply, agricultural rents end up being lower. Besides, the country may be faced with environmental issues, attributed to deforestation. Plantation policies are then initiated. We use the forest stock in 1985 to represent this scarcity.

#### Demographic transition

Over the long run, population and forest trends are strongly related (Mather and Needle, 2000). Population growth puts pressure on natural resources such as the forest. This leads to deforestation and agricultural expansion. Hence, the occurrence of a turning point can be triggered by a slower population growth. This is the demographical transition, often observed after the first steps of development. Thus, population growth and density are two variables that are tested in our model.

#### Institutions

There are several explanations by which better institutions can foster a FT. On the one hand, it may happen through the instigation of well-defined property rights, or with public policies that favor forest preservation/plantations, or even by implementing appropriate trade policies. On the other hand, corruption is widely recognized as a major determinant of deforestation (Amacher, 2006). We therefore tested the influence of the quality of institutions with a variable referred to as "control of corruption". This variable is defined as capturing perceptions of the extent to which public power is exercised for private gain, including both petty and grand forms of corruption, as well as "capture" of the state by elites and private interests[4]. Less corruption may promote the occurrence of a turning point and help to preserve forest area during development. On the contrary, corrupt countries may accentuate deforestation and agricultural land expansion.

### Agricultural rents

As seen before, the land-use trade-off mainly pits agriculture and forest against each other in terms of rents. In the early stages of development, agricultural rents are very high since the demand is important, the cost of labor is low and the market is undeveloped. In our model, we use agricultural prices as a proxy of agricultural rents. Agricultural prices are computed as the value of agricultural exports per hectare. The same variable for forest rents could have been used, but involved too many missing values. Higher agricultural prices are expected to boost agricultural rents and thus favor agricultural land expansion. Both the probability of ending deforestation and the remaining forest area are assumed to decrease as a result.

### Globalisation

As a result of the increase in ecological awareness, economic reforms and the expansion of tourism, globalization can accelerate the FT (Meyfroidt and Lambin, 2011). However, trade openness can also imply leakage. Indeed, an open economy can design its forest preservation policy by specializing itself in non-forest intensive production. The country then imports both agricultural and forest products, and experiences a FT. On the contrary, a country can build its economic development on the exploitation of its forests by exporting goods that require the intensive use of the forest. A well-known example is the case of Indonesia that exports oil palm, soy and forest products. This policy design leads to deforestation. Thus, it is hypothesized that when exports are increased, the probability of experiencing a turning point and preserving less forest area is decreased. We used both trade flows (i.e., imports and exports) as potential factors of deforestation.[5]

## 5 Empirical application: ending deforestation and land-use analyses

In this section, we estimate a switching SUR model to identify the determinants of forest transition and cumulative deforestation. We first present estimation results of the probit model that explain the probability of a turning point occurring, followed by the results of the SUR model that explain the variation of land uses in two different regimes (before and at the turning point).

[4]We used the World Bank index (from the Worldwide Governance Indicators WGI project) since it is the most appropriate. One other indicator, also widely used in the literature, is provided by Freedom House. However, the latter considers people's freedom rather than government corruption. Hence, its effect is rarely significant in studies on deforestation. The Worldwide Governance Indicators report on six broad dimensions of governance (including control of corruption) for over 200 countries over the period 1996-2011. In line with Barbier et al. (2005), we attributed the 1996 value to the three years of observation for each country.

[5]We could have used agricultural trade variables. However, those variables would have involved too many missing values. Moreover, (global) imports and exports are appropriate for our analysis since it focuses on the global macroeconomic determinants of total deforestation.

## 5.1 Probability of ending deforestation

As explained above, the probability of a turning point occurrence is modeled by a probit model and estimated for the years 1990, 2000 and 2005. Since the value of coefficients of binary outcome models, such as probit, cannot be interpreted, we provide averaged marginal effects[6]. Table 2 presents the results and highlights the determinants of the end of deforestation. The probit model is globally better explained in 2005 ($R^2$=0.743) since all of the 15 countries had experienced their turning point (FT=1) by that time. In contrast, only nine countries had experienced a turning point by 1990.

[ Table 2 here ]

We can first observe that we find evidence of the two paths described in Section 2. GDP growth (in 2005) tends to increase the probability of experiencing a turning point. Scarcity (represented by forest stock in 1985) has a direct impact on the probability of occurrence for the three periods (1990, 2000, 2005). As expected, a larger forest cover in the previous periods decreases the probability of ending deforestation at the current period. These two results support the *economic development* and *forest scarcity* paths identified by Rudel et al. (2005).

The variable, "control of corruption", has a significant influence on the probability of ending deforestation. We see that when this index increases for the three years of observations, the probability of experiencing a turning point increases as well. In 2005, an increase of one unity of the corruption index (i.e., better state of corruption) led to an increase of 30 points of percentage of the probability of observing a turning point.

Other factors are determinant in the occurrence of a turning point. First, when population growth increases, the probability decreases. For example, a rise of one point of the population growth rate in 2005 decreased the probability of ending deforestation by 21 points. This suggests that reducing pressure on forests is more difficult for countries that are still in their demographic transition. When agricultural prices increase, the probability of observing a turning point then decreases, but this relationship is only significantly different from zero for the year 2000. Finally, trade variables have several effects on the turning point. Indeed, as expected, if a country is able to import food and natural resources (including timber), it will be more likely to end deforestation (significantly different from zero at the 5% level in 2005). More precisely, an increase of one point of the share of imports in the total GDP increases the probability of experiencing a turning point by a little more than one point. On the contrary, a larger share of exports in the GDP significantly decreases the probability of a turning point (at the 10% level in 2005). This result suggests a leakage effect at the international level: by importing food and timber, some countries indirectly tend to "export their deforestation" problem toward other developing countries.

## 5.2 Land-use analysis

In this section, we present the estimation of the system of land-use share equations for the two regimes ($FT = 0$ and $FT = 1$). We use estimation procedures adapted to panel data, i.e., accounting for individual (country) specific effects (representing unobserved country heterogeneity). There is thus a potential problem of endogeneity since these

[6]For computing marginal effects, the expressions of the sample means of the data can also be evaluated, instead of the sample average of the individual marginal effects. In the case of small samples like ours, the results can be different. Current practice favors our solution whenever it is possible to do (Greene, 2003).

effects may be correlated with some of the explanatory variables. The "within transformation" procedure consists in subtracting individual means from all variables on both sides of the equations. Thus, individual effects are eliminated, preventing any correlation. The transformed equations are then estimated by the SUR method.

It is also possible to estimate the system of equations without eliminating individual effects. However, this may lead to inconsistent estimates if regressors are correlated with these effects. Consequently, we performed a Hausman test whose result indicates that $H_0$ (i.e., there is no correlation between regressors and individual effects) is significantly and highly rejected (at the 1% level). Thus, the appropriate procedure is to estimate within-SUR models. Table 3 presents estimation results for the land-use models, both at the turning point and during the deforestation stage.

[ Table 3 here ]

First of all, it must be noted that the econometric analysis of developing countries having experienced a turning point was made difficult by the low number of observations. Indeed, FT is a long-term process and only 15 countries experienced a transition over the period 1985-2005. Since land-use share equations $S_{iF1}$ and $S_{iA1}$ only concern those countries, the number of observations may be low. However, it can be observed that our approach makes it possible to mitigate this problem since we estimate a panel data model that increases observations compared to cross-section analysis. Moreover, it should be recalled that the land-use model focuses on cumulative deforestation since it analyzes the remaining forest cover after a turning point. As a consequence, it does not make sense to include the scarcity variable. This hypothesis can be considered as the exclusion restriction necessary to identify the switching model non-parametrically. Finally, the coefficient associated with the "control of corruption" variable cannot be identified because the within transformation has the consequence of eliminating all time-invariant variables.

Some important information can be derived from this set of results. It is important to note that factors that influence forest cover and land use after a turning point ($FT = 1$) are not necessarily the same as factors that influence it before the occurrence of the turning point ($FT = 0$), which is proof of the relevance of our "switching regime" approach. Moreover, the significance of the coefficients of the inverse Mill's ratio in the regime $FT = 1$ confirms the presence of sample selection and the appropriateness of a Heckman-type model.

Estimation results provide several interesting insights into the determinants of cumulative deforestation. First, while GDP growth positively influences the occurrence of a turning point, it does not seem to influence the forest cover when this turning point has been reached. Moreover, GDP per capita tends to increase the forest cover after the turning point (while being significantly negatively related to it before the turning point). Economic development thus seems to have a positive influence on the pace of deforestation and may even tend to reduce cumulative deforestation (after the turning point). It follows that finding a positive relationship between economic development and annual deforestation rates, as is done in many studies, may be misleading. Indeed, higher GDP per capita may increase annual deforestation rates and decrease the forest cover before the turning point, but may reduce the length of the forest transition without having an impact on cumulative deforestation. This result underlines the fact that our approach makes it possible to consider patterns of deforestation that are different and more long-term oriented than the usual studies focusing on annual deforestation rates.

Second, population growth tends to have a significant and positive influence on the forest cover after the turning point (with a value of 0.435), while it tends to decrease the probability of the occurrence of a turning point. Population growth thus seems to have complex interactions with deforestation, making the deforestation phase last longer but with a smaller amount of cumulative deforestation. Besides, population density negatively influences the forest cover only before the occurrence of a turning point (with a value of -0.003), but not after. Overall, our results suggest that population issues may not be such a crucial concern in terms of the long-term patterns of deforestation.

Third, we also found evidence that trade has an impact on the total amount of deforestation in a way that is consistent with our leakage hypothesis. The positive coefficient of the "Imports" variable (0.035) indicates that an import-based economy preserves more forest area at the turning point. In contrast, we did not find evidence that an export-based economy loses more forests during the development phase.

Finally, it is interesting to note that the variables that influence the forest cover tend to influence agriculture in the same manner. In the literature on land use and deforestation, it is generally considered that forests and agriculture are complementary. Agricultural expansion is sometimes even used as a proxy for deforestation. Our result shows that this might not be exactly the case on the long term, depending on the development stage considered and the fact that other land uses such as urbanization may also play a role. A land-use approach may then help us to better understand the patterns of land-use allocation and deforestation.

# 6 Discussion

In this paper, we analyze the patterns of cumulative deforestation in developing countries that appear to have experienced a turning point in their forest cover, from deforestation to afforestation. Although a great deal of heterogeneity between countries from one continent to another may exist when analyzing FT (Culas, 2012), this study focuses on common macroeconomic patterns of FT. In other words, our aim was to identify the global transmission channels of cumulative deforestation.

Using a panel dataset of 68 developing countries, we adopted a two-step approach: we first considered which factors influence the probability of occurrence of a turning point over the period 1985-2005, and then analyzed which factors have an impact on the land use at the turning point and during the first stage of FT. Depending on the variables, several paths of cumulative deforestation emerge.

First, economic development plays an important role in the cumulative path of deforestation. Indeed, a country with higher GDP growth is more likely to experience a turning point and an end to deforestation. This result supports the development path hypothesis (Rudel et al., 2005). Countries can more easily intensify agriculture and switch to the industrial sector during periods of economic development. Pressure on remaining forest then decreases. In addition, our model shows that, *ceteris paribus*, a more developed country experiencing a turning point will maintain more forest area than a less developed one (Fig. 2). Whereas economic development may be related to higher periodic deforestation, it is not true from a cumulative point of view since it promotes the occurrence of a turning point and reduces the total loss of forests.

[ Fig. 2 here]

Second, our results support the *scarcity path* hypothesis (Rudel et al., 2005) since more extensive forest cover tends to reduce the future probability of a turning point.

Third, population growth may slow down the transition since it decreases the probability of experiencing a turning point in the long run. This is in line with insights into demographic transitions. Population pressure on resources finally decreases when the growth rate slows down. However, we also found that this variable has a positive influence on the forest cover after the turning point (Figs. 2 and 3).

[ Fig. 3 here ]

Fourth, we found evidence that leakage may take place at the international level: importing countries experience a shorter deforestation phase and smaller cumulative deforestation, while exporting countries experience a longer deforestation phase and higher cumulative deforestation. In other words, we are confronted with a trade-environment nexus in which imports tend to preserve a country from depletion of its natural resources, while implying strong economic concerns such as trade deficits.

## Agriculture and forest vs. "other" land uses

Explaining land use at the turning point, we find that the increase in agricultural prices leads to lower shares of both forest and agricultural area (Figs. 2 and 3). This result suggests that after the first development steps, agricultural profits promote a non-forest non-agricultural land-use type. This corresponds to macroeconomic patterns such as urbanization. In these stages, agricultural production is more intensified and less productive lands are abandoned. In addition, urban development requires space and ends up encroaching on abandoned land.

At the turning point, both population growth and the share of imports increase agricultural and forest land uses (see Figs. 2 and 3 again). Other land uses then decrease. This initially suggests that population growth still induces agricultural land expansion, for food in particular. However, this expansion no longer takes place in the forest. In accordance with Mather and Needle (2000), our results show that at this stage of development (i.e., expanding forest areas), the relationship between forests and agriculture is no longer inverted. Wealthier people and governments are more concerned about forest conservation and environmental issues. Forests and population then follow the same trend. In addition, increasing the share of imports in the GDP leads to the same pattern, making it possible to release the pressure on the forest by importing forest products or disseminating environmental ideas. It is also a sign of participation in the global market, which can provide new harvest technologies and increase agricultural lands.

## REDD+ and public policies

Since scarcity favors the end of deforestation, one good strategy to fight against cumulative deforestation would be to boost the marginal value given to forests. Some good tools to do this could include environmental public policies such as REDD+, or could take the form of agroforestry projects that favor sustainable GDP growth (Simonet and Wolfersberger, 2013).

Our results concerning economic development are relevant when considering international negotiations on reducing deforestation. Indeed, fighting deforestation does not necessarily have adverse effects on development or the search for economic growth. Using a long-term view, we can see that development and forest objectives are not necessarily conflicting. However, we show in this paper that economic development may increase annual rates of deforestation without necessarily increasing (and potentially decreasing) cumulative deforestation. In this context, adapting REDD payments to periodic deforestation could penalize countries with higher GDP growth rates, which would eventually lead them to undergo shorter forest transitions.

The importance of dealing with deforestation on a global scale in order to avoid international leakage on deforestation is also emphasized by our results. One basic intuition about REDD+ and leakage is highlighted here. Indeed, a country can design its policy to receive international funding and to end deforestation while, at the same time, "exporting" deforestation towards other countries through wood and food imports. International agreements on the trade of wood and agricultural products are thus a very important complement to REDD+ implementation. For example, the European Union established the FLEGT ("Forest Law Enforcement, Governance and Trade") in 2003. This program aims at fighting illegal logging, notably by promoting the trade of legally produced timber.

Overall, five main results are highlighted in this paper: (1) considering cumulative deforestation instead of periodic deforestation provides major new information; (2) economic development does not seem to be in conflict with forest preservation on the long term; (3) deforestation issues must be thought out in relation to international trade and leakage issues; (4) population and forest trends remain related over the long run, but in a more complex manner; (5) land-use competition between agriculture and forest may be less severe after the first steps of development.

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Figure 1: Long-term land use and Forest Transition

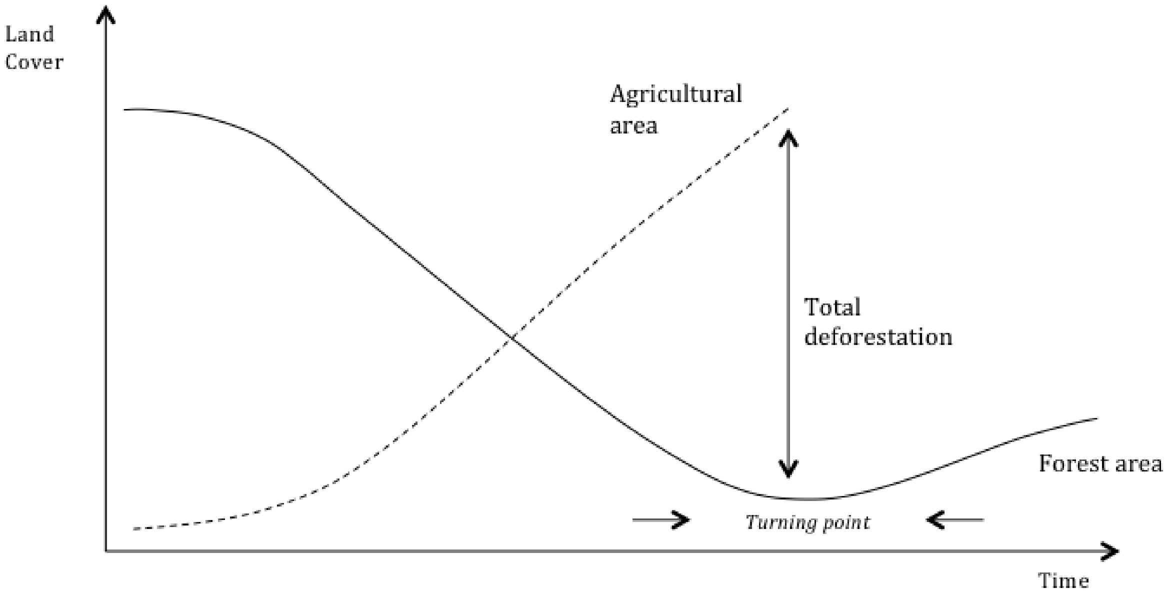



Figure 2: Macroeconomic determinants of the forest cover at the turning point

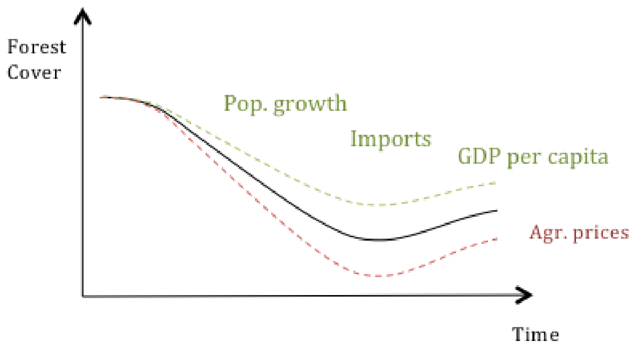


Figure 3: Macroeconomic determinants of the agricultural cover at the turning point

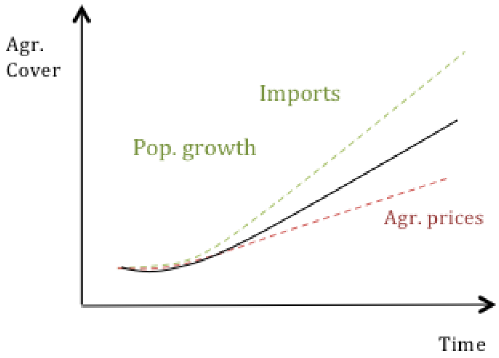


Table 1: Countries observing a turning point

| **Country** | **Cross-references** | **Reports** |
|---|---|---|
| Albania | - | FAO (2010) |
| Bhutan | Meyfroidt et al. (2010a,b) | FAO (2010) |
| Chile | Mather (1992) | FAO (2010) |
| China | Mather (1992); Meyfroidt et al. (2010a,b); Rudel et al. (2005) | FAO (2002) |
| Costa Rica | Meyfroidt et al. (2010a,b); Rudel et al. (2005) | FAO (2010) |
| Cuba | Mather (1992); Rudel et al. (2005) | FAO (2010) |
| Dominican Republic | Rudel et al. (2005) | FAO (2004) |
| India | Meyfroidt et al. (2010a,b); Rudel et al. (2005) | FAO (2002) |
| Korea, South | Rudel et al. (2005) | - |
| Morocco | Mather (1992); Rudel et al. (2005) | FAO (2010) |
| Romania | - | FAO (2010) |
| Thailand | Mather (1992) | FAO (2002) |
| Turkey | - | FAO (2010) |
| Uruguay | - | FAO (2002) |
| Vietnam | Mather (1992); Meyfroidt et al. (2010a,b) | FAO (2010) |

Table 2: Estimation results of the forest transition equation (Probit model)

| Variable | Year=1990 | | Year=2000 | | Year=2005 | |
|---|---|---|---|---|---|---|
| | Estimated coeff. | Marginal effect | Estimated coeff. | Marginal effect | Estimated coeff. | Marginal effect |
| GDP per capita/$10^3$ | -0.019 | -0.002 | 0.045 | 0.005 | 0.127 | 0.010 |
| | (0.119) | (0.013) | (0.101) | (0.012) | (0.154) | (0.011) |
| GDP growth | 0.020 | 0.002 | 0.144 | 0.018 | 0.440** | 0.033*** |
| | (0.068) | (0.007) | (0.118) | (0.014) | (0.210) | (0.010) |
| Forest stock (1985) | -1.072** | -0.117*** | -0.669** | -0.082*** | -1.421** | -0.108*** |
| | (0.500) | (0.043) | (0.314) | (0.033) | (0.663) | (0.031) |
| Control of corruption | 1.674* | 0.182** | 2.097** | 0.258*** | 3.865** | 0.295*** |
| | (0.966) | (0.094) | (0.823) | (0.080) | (1.800) | (0.083) |
| Population density | 0.002 | 0.000 | 0.002 | 0.000 | 0.004 | 0.000* |
| | (0.002) | (0.000) | (0.002) | (0.000) | (0.003) | (0.000) |
| Population growth | -0.994** | -0.108*** | -1.188*** | -0.146*** | -2.711** | -0.207*** |
| | (0.492) | (0.044) | (0.427) | (0.040) | (1.319) | (0.066) |
| Agricultural prices | -0.002 | 0.000 | -0.003* | -0.004** | -0.004 | -0.000 |
| | (0.002) | (0.000) | (0.002) | (0.002) | (0.003) | (0.000) |
| Imports | -0.008 | -0.001 | 0.043 | 0.005 | 0.157** | 0.012*** |
| | (0.056) | (0.006) | (0.040) | (0.005) | (0.076) | (0.012) |
| Exports | 0.009 | 0.000 | -0.050 | -0006 | -0.119* | -0.009** |
| | (0.069) | (0.007) | (0.038) | (0.004) | (0.068) | (0.004) |
| Intercept | 1.548 | | 1.149 | | -1.697 | |
| | (1.343) | | (1.367) | | (2.283) | |
| N | 62 | | 66 | | 65 | |
| Log-likelihood | -12.5174 | | -15.037 | | -9.034 | |
| Pseudo-$R^2$ | 0.513 | | 0.559 | | 0.743 | |

Notes: Standard errors are given in parentheses.

*, ** and *** indicate significance at 10%, 5% and 1%, respectively.

Table 3: Estimation results of land-use models according to the FT regimes

| | FT=1 | | FT=0 | |
|---|---|---|---|---|
| | Forest share | Agri. share | Forest share | Agri. share |
| GDP per capita/$10^{-3}$ | 0.064* | 0.041 | -0.029* | -0.024 |
| | (0.033) | (0.033) | (0.016) | (0.016) |
| GDP growth | -0.007 | -0.009 | -0.011** | -0.008 |
| | (0.015) | (0.014) | (0.006) | (0.006) |
| Population density | 0.001 | 0.003 | -0.003** | -0.002** |
| | (0.004) | (0.004) | (0.001) | (0.001) |
| Population growth | 0.451*** | 0.568*** | 0.135*** | 0.098** |
| | (0.173) | (0.182) | (0.043) | (0.040) |
| Agricultural prices | -0.004*** | -0.004*** | -0.001 | -0.001 |
| | (0.001) | (0.002) | (0.001) | (0.001) |
| Imports | 0.034*** | 0.033*** | 0.001 | 0.005* |
| | (0.009) | (0.009) | (0.003) | (0.003) |
| Inv. Mill's ratio | -0.319* | -0.340* | -0.100 | -0.048 |
| | (0.191) | (0.206) | (0.074) | (0.090) |
| $R^2$ | 0.624 | 0.642 | 0.144 | 0.083 |
| N | 38 | | 155 | |
| Log-likelihood | 54.981 | | 109.022 | |

Notes: Estimation of fixed effects panel data SUR models.

*, ** and *** indicate significance at 10%, 5% and 1%, respectively.

Standard errors are given in parentheses.

Appendix A. Database Description

| **Variables** | **Definition** | **Source** |
|---|---|---|
| Forest area | Forest area, thousands of hectares | FAO |
| Agricultural area | Forest area, thousands of hectares | FAO |
| FT | 1 if Forest Transition, 0 otherwise | - |
| GDP Per Capita | Thousands of dollars (2005 constant prices) | PWT 7.0 |
| GDP growth | GDP per capita annual growth rate | World Bank |
| Control of corruption | World Governance Indicator project | World Bank |
| Population density | People per sq. km of land area | FAO |
| Population growth | Population annual growth rate | World Bank |
| Agricultural prices | Agri. products export value per hectare | FAO |
| Imports | Imports of goods and services (% of GDP) | World Bank |
| Exports | Exports of goods and services (% of GDP) | World Bank |

Appendix B. Country list

| | | | | |
|---|---|---|---|---|
| Albania | Argentina | Bangladesh | Belize | Benin |
| Bhutan | Bolivia | Botswana | Brazil | Burkina Faso |
| Cambodia | Cameroon | Central African Republic | Chad | Chile |
| China | Colombia | Congo, Dem. Rep. | Congo, Rep. | Costa Rica |
| Cuba | Dominican Republic | Ecuador | Equatorial Guinea | Ethiopia |
| Ghana | Guatemala | Guinea | Honduras | India |
| Indonesia | Ivory Coast | Korea, Republic of | Laos | Liberia |
| Madagascar | Malawi | Malaysia | Mali | Mexico |
| Morocco | Namibia | Nepal | Nicaragua | Nigeria |
| Panama | Papua New Guinea | Paraguay | Peru | Philippines |
| Romania | Rwanda | Senegal | Sierra Leone | Solomon Islands |
| Sri Lanka | Sudan | Suriname | Tanzania | Thailand |
| Togo | Turkey | Uganda | Uruguay | Venezuela |
| Vietnam | Zambia | Zimbabwe | | |

Table 4: All countries

| **Variable** | **Mean** | **Std. Dev.** | **Min.** | **Max.** | $N \times T$ |
|---|---|---|---|---|---|
| Forest area | 29991.604 | 71970.413 | 34.9 | 574839 | 204 |
| Agricultural area | 33619.581 | 74817.034 | 68 | 532203 | 204 |
| GDP per capita | 3817.409 | 3659.837 | 117.227 | 22808.089 | 204 |
| GDP growth | 3.87 | 6.028 | -51.031 | 25.7 | 201 |
| Control of corruption | -0.449 | 0.594 | -1.566 | 1.542 | 204 |
| Population density | 91.191 | 149.749 | 1.719 | 1080.033 | 204 |
| Population growth | 2.046 | 0.951 | -1.501 | 4.906 | 204 |
| Agricultural prices | 61.914 | 212.486 | 0.15 | 1957.054 | 204 |
| Imports | 36.937 | 17.302 | 4.631 | 100.597 | 201 |
| Exports | 32.671 | 19.857 | 4.021 | 119.81 | 201 |

Notes: $N = 68$ countries and $T = 3$, unbalanced panel dataset.

Table 5: Countries observing a turning point

| **Variable** | **Mean** | **Std. Dev.** | **Min.** | **Max.** | $N \times T$ |
|---|---|---|---|---|---|
| Forest area | 24293.079 | 48184.598 | 769 | 193043.906 | 38 |
| Agricultural area | 66429.850 | 145895.747 | 454 | 532203 | 38 |
| GDP per capita | 6484.945 | 4623.285 | 941.844 | 22808.089 | 38 |
| GDP growth | 5.372 | 3.735 | -5.454 | 11.3 | 38 |
| Control of corruption | 0.058 | 0.658 | -0.824 | 1.542 | 38 |
| Population density | 135.614 | 123.365 | 11.883 | 497.037 | 38 |
| Population growth | 1.141 | 0.743 | -0.233 | 2.82 | 38 |
| Agricultural prices | 83.228 | 106.121 | 1.516 | 441.73 | 38 |
| Imports | 35.349 | 15.922 | 8.548 | 74.687 | 38 |
| Exports | 31.308 | 14.325 | 7.134 | 73.568 | 38 |

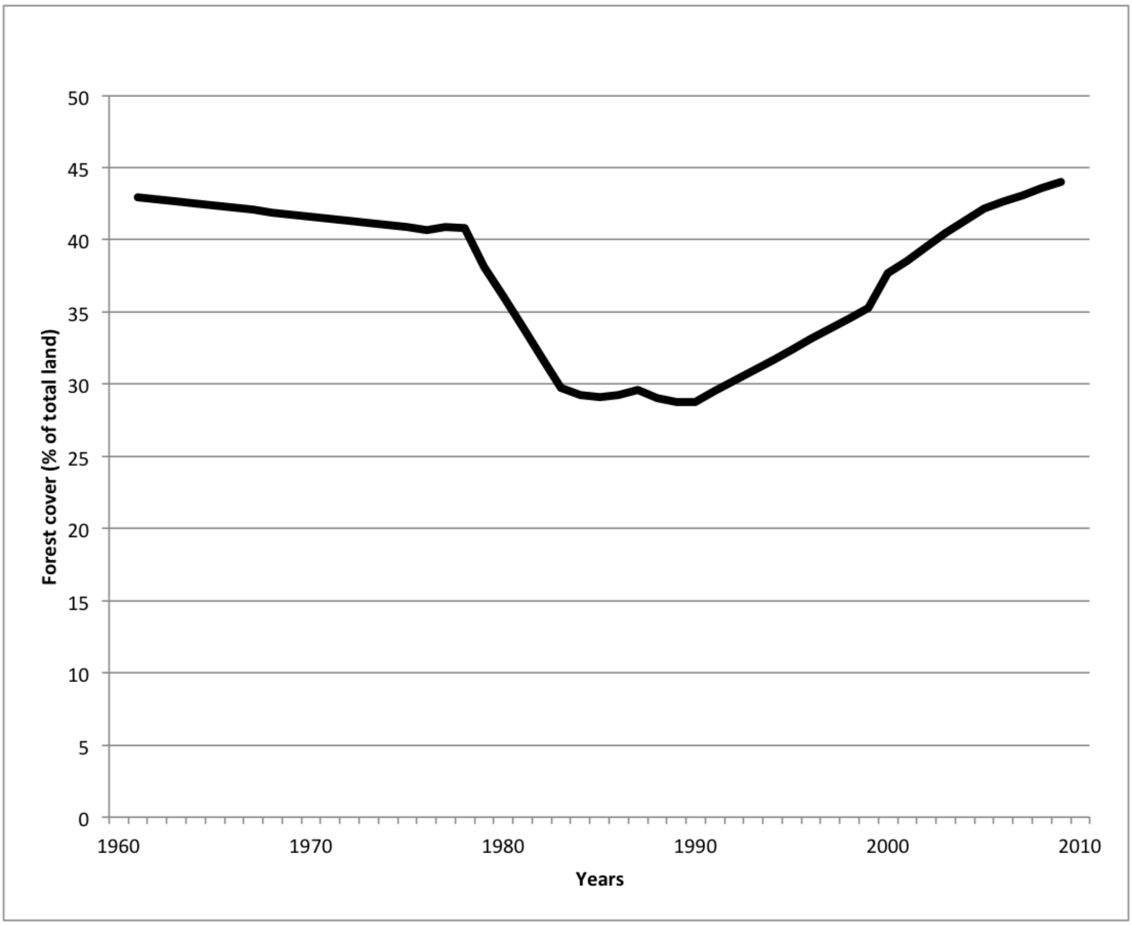
Notes: $N = 15$ countries in 2005 and $T = 3$, unbalanced panel dataset.

Table 6: Countries still deforestating

| Variable | Mean | Std. Dev. | Min. | Max. | $N \times T$ |
|---|---|---|---|---|---|
| Forest area | 31296.086 | 76438.364 | 34.9 | 574839 | 166 |
| Agricultural area | 26108.797 | 42531.452 | 68 | 264500 | 166 |
| GDP per capita | 3206.769 | 3110.005 | 117.227 | 15411.485 | 166 |
| GDP growth | 3.52 | 6.405 | -51.031 | 25.7 | 163 |
| Control of corruption | -0.565 | 0.514 | -1.566 | 0.759 | 166 |
| Population density | 81.022 | 153.681 | 1.719 | 1080.033 | 166 |
| Population growth | 2.253 | 0.87 | -1.501 | 4.906 | 166 |
| Agricultural prices | 57.035 | 229.989 | 0.15 | 1957.054 | 166 |
| Imports | 37.307 | 17.634 | 4.631 | 100.597 | 163 |
| Exports | 32.988 | 20.961 | 4.021 | 119.81 | 163 |

Notes: $N = 53$ countries and $T = 3$, unbalanced panel dataset.

Appendix D. Time-series of net forest cover in Vietnam: an empirical example of Forest Transition.




Data source: FAO

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