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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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Abstract

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1 Introduction

Deforestation is one of the major factors enhancing climate change, and also generates desertification, erosion of soil or extinction of biodiversity. In this context, major improvements in the global understanding of deforestation issues are still required. So far, the empirical literature on the topic (Among many others, most recent work encompasses Arcand et al. (2008); Combes Motel et al. (2009); Culas (2007); Damette and Delacote (2011); Nguyen-Van and Azomahou (2007); Scriecu (2007)) has provided useful results but was focused on factors explaining periodical deforestation rates (annual deforestation rates or five-years rates). Yet, it is important to understand the deforestation patterns on the whole development path, and not only periodic ones.

In developing countries, land-use competition occurs mainly between agriculture and forests. Agricultural expansion represents the major direct cause of deforestation. Hence, a better understanding of the cumulative nature of deforestation requires to highlight the determinants of the land allocation - agriculture or forest - on the long-run.

The Forest Transition (FT) hypothesis is the adequate 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 turning point then occurs when the forest area reaches a minimum in the country. This point is of particular interest, as it allows to consider cumulative deforestation of a nation all over its development path. Then, the turning point provides structural information about the whole deforestation stage. In addition, explaining the occurrence of turning point helps understanding which macroeconomic factors facilitate deforestation ending.

This paper develops three main points. First, we model the probability, for a developing country, to experience a turning point over the period 1985-2005. The objective is to highlight the determinants of the end of deforestation in a given developing country. Second, we focus on the determinants of the land-use at the turning point. Therefore, the factors of cumulative deforestation are highlighted. We thus bring new evidence to better understand why some turning points occur at a relatively high level of forest area (France: 14% of total land) or on the contrary others occur once the whole forests have been cut in the country (Ireland: 2% of total land). Third, we estimate the determinants of land-use for countries which are still in a deforestation regime. Our results may help public policies to make future turning points occur earlier in length with higher forest area remaining. For this purpose, we use a switching seemingly unrelated regression (SUR) model, which consists of estimating a system of land-use shares panel data for two different regimes: (1)

when the developing country has experienced a turning point and (2) when the developing country is still deforesting.

The next section presents the FT hypothesis. Section 3 details the interests of studying turning points and their related land-uses shares. Data and econometric methodology are presented in Section 4. Section 5 exposes the results. Discussion is given in section 6.

2 Land-use and the Forest Transition hypothesis

The Forest Transition hypothesis (Mather, 1992) asserts that forests *"change in predictable ways as societies undergo economic development, industrialization and urbanization"* (Rudel et al., 2005). At the beginning of the development phase, forests are abundant and a major phase of deforestation arises. Then, a phase of stagnation appears and the turning point occurs. Finally a phase of reforestation takes place. The evolution of the forest cover thus follows an inverted J-shaped, while agriculture follows the opposite evolution (Figure 1).

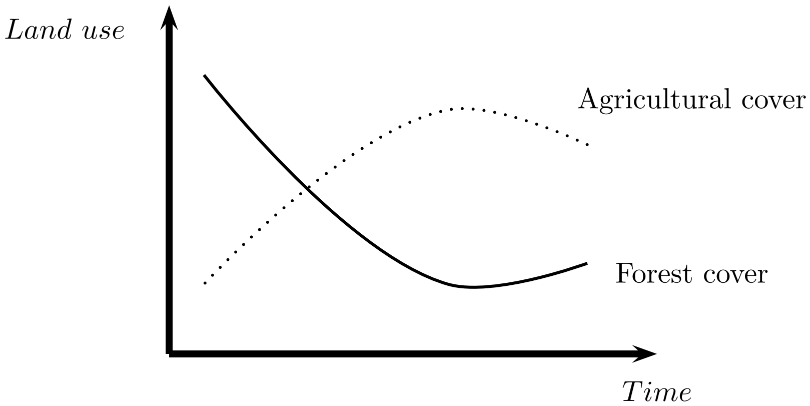


Figure 1: Evolution of land-uses in the Forest Transition hypothesis

Two main paths explain the FT hypothesis: the *economic development* path and the *forest scarcity* path (Rudel et al., 2005). The *economic development path* begins with agricultural expansion and fast deforestation phase in a country. Then, deforestation decreases, as the agriculture intensifies. Finally, once achieved a certain level of income per capita and capital stock, the country switches from an agriculture-based economy into an industry-based economy. As a consequence, the pressure on remaining forests decreases and deforestation ceases, which determines the turning point. This point also corresponds to agricultural intensification and rural exodus for better-payed urban jobs. 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 test this relationship (Culas, 2012), finding contradictory results (Choumert et al., 2012). However, the development path (1) is specifically related to forests while the EKC concerns any kinds of environmental indicator; (2) considers economic development through sectorial switches (from extensive agriculture to intensive agriculture to industrialization and urbanization), while the EKC focuses on income.

Moreover the FT hypothesis presents a more complete framework than the EKC, including a *forest scarcity path*. This path refers to the comparison of land-use marginal values. At the beginning of the development phase, a country has a relatively important 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 one of agricultural land decreases (as newly converted land is less and less productive), until a point at which both marginal values equalize, which defines the turning point (Barbier et al., 2010). Those two paths may be strongly related as when the scarcity takes place, reforestation is possible (or not) depending on the country's development (Ewers, 2006).

As a conclusion, all along the development phase of a country, land-use competition occurs between agriculture and forests. During the first stages of its development, a country mainly allocate land to agriculture as it provides food and income. Economic development, and/or the lack of forests for environmental services, finally conducts the country to promote forest allocation. Therefore, improving the understanding of the cumulative nature of deforestation requires to better understand the land allocation over the long-run. To do this, the following section details the interest of studying the turning point and then presents the 15 developing countries which have experienced one.

3 Analyzing cumulative deforestation

3.1 Why envisaging deforestation issues through the turning point?

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

This FT approach allows to analyze a country's deforestation all along the whole development phase. At the opposite, main studies often consider deforestation rates over yearly-periods (Arcand et al., 2008; Combes Motel et al., 2009; Culas, 2007; Damette and Delacote, 2011; Nguyen-Van and Azomahou, 2007; Scriecu, 2007). Thus, our approach avoids periodical determinants of deforestation and focuses on structural ones, and thus provides a different point of view of the phenomenon. Two examples illustrate it, with different periodical influences on the deforestation rate. In 1994, the CFA franc has been 50% devaluated. Then, the demand in wood products in the CFA franc area has consequently increased, implying the growth of the deforestation rate over this period. Another example of periodical influence on the deforestation rate is the economic crisis of 2008. This latter has slowed the demand for timber product and then reduced the pressure on remaining forests (FAO, 2009). These two examples show how deforestation may increase or decrease due to periodical effects.

In contrast, at the turning point, cumulative information on deforestation is available as we envisage the whole first stage of FT. Why do some countries experience a turning point at 10% forest cover while other ones experience it at 30%? Focusing on the forest cover at this moment implies identifying which variables 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 the deforestation.

As deforestation results in a trade-off between agriculture and forest, it is useful to analyze the agricultural expansion all along the development phase. Indeed, identifying the macroeconomic variables which explain the total area of agriculture at the turning point can help to preserve more forests before the turning point. Results may thus give insights for countries that have not yet experienced a turning point, in order to help those countries ending deforestation earlier in time and higher in forest cover.

3.2 Developing countries observing a turning point in their forest cover

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

In our sample, 15 countries experienced such an evolution. Of course, even the turning point that has been observed may not be permanent and the selected countries may experience deforestation in the future. Nevertheless, our analysis considers observations in which deforestation ceases, temporarily or permanently. In section D, we present the case of Vietnam, which appears to experience a turning point in its forest cover around 1985-90.

In order to strengthen our empirical observations about a potential turnaround, we check the validity of the 15 countries sub-sample. To do this, we use observations from four main research papers on FT (Mather, 1992; Meyfroidt et al., 2010a,b; Rudel et al., 2005). We also check in several international reports provided by FAO. Table 1 sums up papers where a given country has been cited as observing a FT.

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)

These cross-references consolidate our time-series observations and confirm the existence of a turning point in forest covers in those 15 countries.

4 Land-use and cumulative deforestation in developing countries

4.1 Economic framework

The aim of our model is to illustrate the land-allocation choice all along the development process. Hence, as Barbier et al. (2010), we study land-use focusing on forest versus agriculture. The model we use in this study is similar to classical models of land distribution. We just adapt the conceptual basis from the farmer behavior based on the 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 LC_j thousand of hectares of land type j ($j = 1, ..., J$). The total surface for the country is then $TC = \sum_j LC_j$. We assume that a developing country's representative agent allocates the total surface across different land-uses and chooses the amount of land for each type j. This land allocation depends, among others 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 impact the same way those very diverse set of actors for their land-use choice. Nevertheless relying on such representative agent framework aims at aggregating the diversity of those agents in order to let emerge macroeconomic variable affecting the most land-use choice at the level of the country.

Let $B_j(X_j)$ denote 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:

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

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 formers. 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 is defined a reference category ($j = 0$), namely the surface not devoted to forest ($j = F$) nor to agriculture ($j = A$). The summation in equation (5) is over all land-uses. Applying usual mathematical manipulations, it is possible to drop this reference category. Indeed, the three land-use being complement, we can focus on only two land-uses, the third one being implicitly explained by the results on the two formers. We thus have:

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

In the same way, we can deduce that:

$$S_{i0}^{*} = \frac{1}{1 + \sum_{j=A,F} exp(f_j(X_j))} \tag{7}$$

We estimate the share of both forest and agricultural areas at the turning point (if any). As agriculture expands at the expense of forests, we may expect individual correlations between errors of those two equations. Therefore, we use a Zellner's seemingly unrelated regression (SUR) model.

To trace the factors influencing forest transition, a standard probit model is chosen:

$$\begin{aligned} &FT_i^{*} = W_i\beta + \epsilon_{FTi} \\ &FT = 1 \text{ if } FT_i^{*} > 0 \\ &FT = 0 \text{ if } FT_i^{*} \leq 0 \end{aligned} \tag{8}$$

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

Shares of land-use depend on whether the country is in a deforestation regime or not. Thus we distinguish whether countries experienced a turning point or not. More specifically, we can expect variables that significantly affect the forest cover at the turning point explain cumulative deforestation, which is not the case for variables explaining 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 or not a turning point:

$$Y_{FT=1} : \begin{cases} S_{iF1} = X_{i1}\beta_{F1} + \epsilon_{iF1} \\ S_{iA1} = X_{i1}\beta_{A1} + \epsilon_{iA1} \end{cases} \tag{9}$$

$$Y_{FT=0} : \begin{cases} S_{iF0} = X_{i0}\beta_{F0} + \epsilon_{iF0} \\ S_{iA0} = X_{i0}\beta_{A0} + \epsilon_{iA0} \end{cases} \tag{10}$$

where ϵ_{iF1}, ϵ_{iA1}, ϵ_{iF0} and ϵ_{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 his forest cover ($Y_{FT=1}$) and we estimate shares of land-use at this moment; (2) The country is still deforesting ($Y_{FT=0}$). Explaining land-use during this phase comes to explain both deforestation and agricultural expansion. Hence, the different shares of land-use have different meanings depending on the country's regime. As a consequence, our model have to take this information into account as it introduces correlation between error terms of each system, and with the error term of selection equation ϵ_{FTi}. It follows that:

$$\begin{aligned} E(\epsilon_{iF1}|FT_i^* > 0) &= \rho_{F1}\tfrac{\phi(\psi)}{\Phi(\psi)} \\ E(\epsilon_{iA1}|FT_i^* > 0) &= \rho_{A1}\tfrac{\phi(\psi)}{\Phi(\psi)} \\ E(\epsilon_{iF0}|FT_i^* \leq 0) &= -\rho_{F0}\tfrac{\phi(\psi)}{1-\Phi(\psi)} \\ E(\epsilon_{iA0}|FT_i^* \leq 0) &= -\rho_{A0}\tfrac{\phi(\psi)}{1-\Phi(\psi)} \end{aligned} \tag{11}$$

where $\frac{\phi(\psi)}{\Phi(\psi)}$ and $-\frac{\phi(\psi)}{1-\Phi(\psi)}$ are the inverse Mills ratio for the probit model, with $\psi = W_i\beta$ and ρ_{F0}, ρ_{A0}, ρ_{F1} and ρ_{A1} the parameters to be estimated. ϕ and Φ are respectively the density and distribution functions of the standard normal. Consequently, in that case, both ordinary and generalized least squares estimation of systems (9) and (10) yield inconsistent estimates. To correct it, we use above results to adjust conditional mean error term at zero.

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

$$Y_{FT=1} : \begin{cases} S_{iF1} = X_{i1}\beta_{F1} + \rho_{F1}\frac{\phi(\psi)}{\Phi(\psi)} + \nu_{iF1} \\ S_{iA1} = X_{i1}\beta_{A1} + \rho_{A1}\frac{\phi(\psi)}{\Phi(\psi)} + \nu_{iA1} \end{cases} \tag{12}$$

$$Y_{FT=0}: \begin{cases} S_{iF0} = X_{i0}\beta_{F0} - \rho_{F0}\frac{\phi(\psi)}{1-\Phi(\psi)} + \nu_{iF0} \\ S_{iA0} = X_{i0}\beta_{A0} - \rho_{A0}\frac{\phi(\psi)}{1-\Phi(\psi)} + \nu_{iA0} \end{cases} \quad (13)$$

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 β of equation (8) are consistently estimated by estimating a probit for each period (1990, 2000 and 2005), and then saving the inverse Mills ratio. In a second step, we estimate the SUR models (12) and (13) (that include the inverse Mills ratio) by a procedure adapted to panel data, which we detail below.

4.3 Data description

We lead our analysis on a panel data set. Each country is observed over 3 years: 1990, 2000, 2005. We keep only these three years as they are non-extrapolated points from FAO. Thus we can expect a higher reliability. Details on both explained and explanatory variables are given below.

4.3.1 Dependent variables

Turning point variable

This is the dependent variable of the first step of the model. This is an observed state variable: experiencing or not a turning point over 1985-2005. It is a dummy taking 1 if the country has experienced a turning point (FT=1), 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). From equations (14) and (7), we can write:

$$\ln\left(\frac{S^*_{ij}}{S^*_{i0}}\right) = f_j(X_j), \quad j = F, A \quad (14)$$

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 built as $ln(S^*_F/S^*_0)$ and $ln(S^*_A/S^*_0)$, respectively.

4.3.2 Control variables

Income variables

Economic development may have two different impacts. Over the short-run, a country converts its forest into agricultural land to develop itself. However, over the long-run, the GDP per capita

(GDPPC) and its growth (GDPG) are expected to promote a turning point occurrence (i.e. economic development path) and preserve more forest area. Also, a more developed country proceeds to agricultural intensification and needs less agricultural area at the turning point.

Forest scarcity

Forests play major roles in environmental services and regulation. For example, China, after a long phase of deforestation, faced of environmental issues related to a forest scarcity (Meyfroidt et al., 2010a). Finally the country had to implement reforestation policies. Hence, a larger forest stock in 1985 (FC85) is expected to be related to smaller probability of a turning point occurrence over 1985-2005.

Demographic variables

Trends of population and forest may be strongly related (Mather and Needle, 2000). Population puts pressure on forests, for food, income, space and energetic needs. Larger population density (POPDENS) and population growth (POPG) are hypothesized to slow the end of the deforestation and imply both more forest loss and larger agricultural needs.

Institutions

Corruption and poor institutions can be a strong determinant of deforestation (Amacher, 2006). We test the influence of institutional quality with *"political rights"* and *"civil liberties"* variables, both provided by the Freedom House. As Bhattarai and Hammig (2001), Damette and Delacote (2011) or Nguyen-Van and Azomahou (2007), we sum up these two variables and compute a global index of political institutions in order to avoid potential collinearity issues. Good institutional quality (INST, low score means high quality) may promote a turning point and preserve more forest area during the development phase.

Agricultural sector variable

In developing countries, agricultural prices remain a strong incentive to deforest for farmers. Thus, the agricultural exports value (PAGR) is included. Agricultural prices are expected to reduce both the turning point probability and the forest area at the turning point, contrary to the agricultural area.

Macroeconomic policy variables

The trade configuration of an economy strongly determines its resources management. In order to obtain income, a country with large natural resources endowment can choose an exporting strategy. Hence, an economy with a GDP highly based on exports (EXPORTS) is expected to experience a turning point later in time, to preserve less forest area and to increase agricultural expansion. At the opposite, countries which import their agricultural products (IMPORTS) are expected to reduce cumulative deforestation.

5 Empirical application: the determinants of forest transition and cumulative deforestation

In this section, we estimate the switching model to identify the determinants of forest transition and cumulative deforestation. We first present estimation results of the probit model explaining the occurrence (or not) of forest transition, and then results of the SUR model explaining the variation of land uses in two different regimes (before and after the turning point).

5.1 Probability of ending deforestation

As explained above, the probability of a turning point occurrence is modeled by a probit and estimated for the years 1990, 2000 and 2005. Table 2 presents the estimation results and highlights the determinants of the end of deforestation. The Probit model is globally better explained in 2005 (R^2=0.584) as at this moment, the all 15 countries have known their turning point (FT=1). At the opposite, in 1990, only 9 countries had experienced a turning point.

We can first notice that we find evidence of the two paths described in section 2. Scarcity (FC85) has a direct impact on the probability of occurrence over the three periods (1990, 2000, 2005). As expected, more forests in the period $t-1$ decreases the probability of ending deforestation at the period t. This result supports the *forest scarcity path* identified by Rudel et al. (2005). GDP per capita (in 2000 and 2005) and economic growth (in 2005) tend to increase the probability to experience a turning point over 1985-2005. This result supports the *economic development path* identified by Rudel et al. (2005): a country is able to experience a turning point when it has reached a sufficient level of development.

Yet, other factors influence the probability of occurrence of a turning point. First, when population growth (POPG) increases, the probability of a turning point occurrence decreases. It suggests that a developing country can not decrease pressure on its forests before ending its demographic transition. Second, *ceteris paribus*, the trade directions have diverse effects. Indeed, as expected, if a country is able to import food and other natural resources (e.g., timber), it will be more likely to

Table 2: Estimation results of the forest transition equation for each observed period

Variable	Year=1990	Year=2000	Year=2005
GDPPC	0.066	0.234**	0.223*
	(0.139)	(0.119)	(0.117)
GDPG	0.068	0.005	0.225**
	(0.065)	(0.095)	(0.093)
FC85	-1.000**	-0.426*	-0.641*
	(0.489)	(0.262)	(0.389)
INST	0.054	0.155	0.083
	(0.092)	(107)	(0.113)
POPDENS	0.408	1.110	0.568
	(2.216)	(1.638)	(1.588)
POPG	-1.016**	-0.817**	-0.980**
	(0.487)	(0.333)	(0.428)
PAGR	0.081	0.048	0.122
	(0.202)	(0.037)	(0.185)
IMPORTS	-0.017	0.048	0.089**
	(0.045)	(0.037)	(0.038)
EXPORTS	0.009	-0.051	-0.072**
	(0.050)	(0.034)	(0.035)
Intercept	-0.753	-2.354	-5.041
	(2.761)	(2.961)	(3.680)
N	62	66	65
R^2	0.422	0.440	0.583

Notes: Estimation of a probit model for each period.
*, ** and *** indicate significance at 10%, 5% and 1% respectively. Standard error are given in parenthesis.

end deforestation (significant at the 5% level in 2005). On the contrary, a larger share of exports in GDP decreases the probability of a turning point (significant at the 10% level in 2005). This result suggests that leakage takes place at the international level: some countries, by importing food and timber, indirectly tend to "import’" deforestation from countries exporting those goods. Eventually, it is interesting to note that the quality of institutions does not seem to help to end deforestation in a given country. Likewise, agricultural prices and population density have no effect on the occurrence of a turning point.

5.2 Land-use analysis

The method to estimate both systems of equations (corresponding to the two regimes) is the Fixed Effects (Within) procedure. Individual effects are eliminated, as they may be correlated with some of the explanatory variables, by subtracting individual means from all variables in both sides of equations. Once variables are demeaned, the equations are estimated by the Seemingly Unrelated Regression (SUR) method. This procedure adapted to panel data is a Within-SURE method. It would be possible to estimate the system of equations using the Random Effects (Generalized Least Squares) procedure, but this leads to inconsistent parameter estimates if regressors are correlated with individual effects[1].

Fixed effects panel data SUR models are estimated for each regime (forest transition or not). Table 3 presents estimation results for the land-use model, at the turning point and during the deforestation stage. A Backward methodology was applied to the land-use analysis in order to test for the robustness of our estimations. Using the Wald test, the less significant variables are removed till we converge to the most fitted model.

This step of the model studies the cumulative deforestation in terms of quantity. 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. Several preliminary information can be derived from this results set. It is important to notice that factors influencing the forest cover and the land use after a turning point ($FT = 1$) are not necessarily the same as factors influencing it before the occurrence of the turning point ($FT = 0$), which gives evidence of the relevance of our approach. Moreover, the significance of three over four coefficients of inverse Mills ratio confirms the presence of sample selection and the appropriateness of a switching model.

[1] In our sample, the Hausman test indicates that H_0 (there is no difference between Random and Fixed Effects coefficients) is highly rejected (significant at 1% level). Then the appropriate estimators are the fixed effects.

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
$GDPPC_{10^{-3}}$	-	-	-0.032***	-0.027*
			(0.012)	(0.014)
GDPG	-	-	-0.010**	-0.008
			(0.005)	(0.005)
$POPDENS_{10^{-3}}$	-	-	-2.743***	-2.164**
			(0.823)	(1.020)
POPG	0.267	0.401*	0.141***	0.113**
	(0.230)	(0.209)	(0.047)	(0.046)
PAGR	-0.345**	-0.327**	-0.146***	-0.073
	(0.159)	(0.145)	(0.049)	(0.052)
IMPORTS	0.036***	0.035***	0.002	0.005*
	(0.013)	(0.013)	(0.003)	(0.003)
Inv. Mills ratio	-0.431**	-0.417**	-0.266*	-0.249
	(0.218)	(0.213)	(0.160)	(0.178)
N	38	38	155	155
R^2	0.496	0.551	0.173	0.091

Notes: Estimation of fixed effects panel data SUR models.
*, ** and *** indicate significance at 10%, 5% and 1%, respectively.
Standard errors are given in parenthesis.

Estimation results bring several interesting insights on determinants of cumulative deforestation. First, while GDP per capita positively influences the probability of occurrence of a turning point, it does not seem to influence the forest cover when this turning point has been reached. Economic development thus seems to have a positive influence on the pace of deforestation (increasing the probability of occurrence of a turning point), but not on cumulative deforestation (no relation to the forest cover remaining after the turning point). It follows that finding a positive relationship between GDP per capita and annual deforestation rates may be misleading: 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 while not influencing cumulative deforestation. This result underlines the fact that our approach allows to consider for patterns of deforestation that are different and more long-term oriented than usual studies focusing on annual deforestation rates.

Second, population growth tends to have a significant and positive influence on the forest cover (with a value of 0.141) only before the occurrence of a turning point, which gives us the opposite type of results than for economic growth: a fast-growing population tend to decrease pace of the forest transition, by decreasing the probability of occurrence of the turning point, but does not seem to have any influence on cumulative deforestation, i.e the forest cover level after the turning point. However, the population growth increases the cumulative agricultural land expansion, which could be an indirect factor of pressure on forest, by influencing the trade-off for land-use or displacing some activities. Besides, population density negatively influences the forest cover before the occurrence of a turning point (with a value of -2.743), but not after. Overall, our results suggest that population issues may not be such a crucial concern concerning the long term patterns of deforestation.

Third, we also find evidence that trade impacts the total amount of deforestation in a way that is consistent with our leakage hypothesis. The positive coefficient of the variable IMPORTS (0.036) indicates that an import-based economy preserves more forest area at the turning point. In contrast, we do not find evidence that an export-based economy lost more forests during the development phase.

Finally, it is interesting noting that the variables influencing the forest cover tend to influence agriculture in the same manner. In the usual literature, it is generally considered that forests and agriculture are complement and agricultural expansion is sometimes used as a proxy for deforestation. Our result shows that this might not be exactly the case, and 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

This paper analyzes the patterns of cumulative deforestation in countries that appear to have experienced a turning point in their forest cover, from deforestation to afforestation. From a 68 countries panel dataset, we adopt a two-step approach: we first consider which factors influence the probability of occurrence of a turning point over 1985-2005, and then analyze 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 arise.

First, economic development plays an important role in the cumulative path of deforestation. Indeed, a country with a higher GDP per capita is more likely to experience a turning point and then ending deforestation. This result supports the *development path* hypothesis (Rudel et al., 2005). Once achieved a certain level of development, the economy intensifies agriculture and switches to the industrial sector and pressure on remaining forest decreases. In addition, our model shows that *ceteris paribus*, a more developed country experiencing a turning point does not save less forest area than anther. Then, while economic development may be related to higher periodical deforestation, it is not strongly related to cumulative deforestation as it promotes a turning point occurrence without reducing the total loss of forests.

Second, our results support the *scarcity path* hypothesis (Rudel et al., 2005) as larger forest cover in $t-1$ is related to smaller probability of a turning point in t. Hence, one good strategy to fight against cumulative deforestation would be to boost the marginal value given to forests. Some good instruments to realize it may be environmental public policies such as REDD+ and/or agroforestry projects (Simonet and Wolfersberger, 2013).

Third, population growth may slow down the transition as over the long run it decreases the probability of experiencing a turning point. However, it does not seem to play a role in cumulative deforestation, as it is not related to the forest cover after the turning point. Overall, this result suggest that population issues influence more the pace of the forest transition than cumulative deforestation.

Fourth, we find evidence that leakage may take place at the international level: importing countries experience smaller cumulative deforestation, while exporting countries experience higher cumulative deforestation. In other words, we are confronted to a trade-environment nexus, in which imports tend to preserve a countries natural resources, while implying strong economics concerns such as trade deficit.

Finally, studying deforestation issues over the long term suggests that agriculture and forest are not so conflicting in the trade-off for land-use once achieved a threshold of development. In fact, the shares of both agricultural and forest area are impacted in the same way by the different macroeconomic variables. It implies that after the first step of development, once industrialization becomes reachable to the country, the trade-off for land-use may mainly oppose both agriculture and forest to other-uses lands (urbanization, barren lands...).

In this context, five main results are to be remembered from this piece of work: (1) considering cumulative deforestation instead of periodical one provides major new information; (2) economic development does not seem to be conflicting with forest preservation over the long run; (3) deforestation issues must be thought in relation to international trade and leakage issues; (4) population pressure remains one determinant of deforestation over the long-run; (5) competition for the land-use between agriculture and forest may be less severe after the first steps of development. Those results are quite relevant when considering international negotiations on reducing deforestation and other REDD + issues. Indeed, our results suggest that fighting deforestation does not necessarily have to have adverse effects on development or the search of economic growth. They also emphasize the importance of dealing with deforestation on a global scale in order to avoid international leakage on deforestation.

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 else	-
GDP	GDP Per Capita (2005 constant prices)	PWT 7.0
GDPG	GDP per capita growth (annual growth rate)	World Bank
INST	Political rights + Civil Liberties	Freedom House
POPDENS	Population density (people per sq. km of land area)	FAO
POPG	Population growth (annual growth rate)	World Bank
PAGR	Agricultural export prices (thousands of dollars)	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
Cote d'Ivoire	Cuba	Dominican Republic	Ecuador	Equatorial Guinea
Ethiopia	Ghana	Guatemala	Guinea	Honduras
India	Indonesia	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		

Appendix C. Descriptive statistics

Table 4: All countries

Variable	Mean	Std. Dev.	Min.	Max.	N
Forest area	39.722	21.471	1.04	94.718	198
Agricultural area	38.333	19.462	0.462	85.465	198
GDPPC	3913.63	3672.175	117.227	22808.089	198
GDPG	3.82	6.09	-51.031	25.7	195
INST	7.879	3.51	2	14	198
POPDENS	92.618	151.742	1.719	1080.033	198
POPG	2.02	0.952	-1.501	4.906	198
PAGR	0.076	0.114	0.001	0.643	198
IMPORTS	37.151	17.402	4.631	100.597	195
EXPORTS	33.121	19.931	4.021	119.81	195

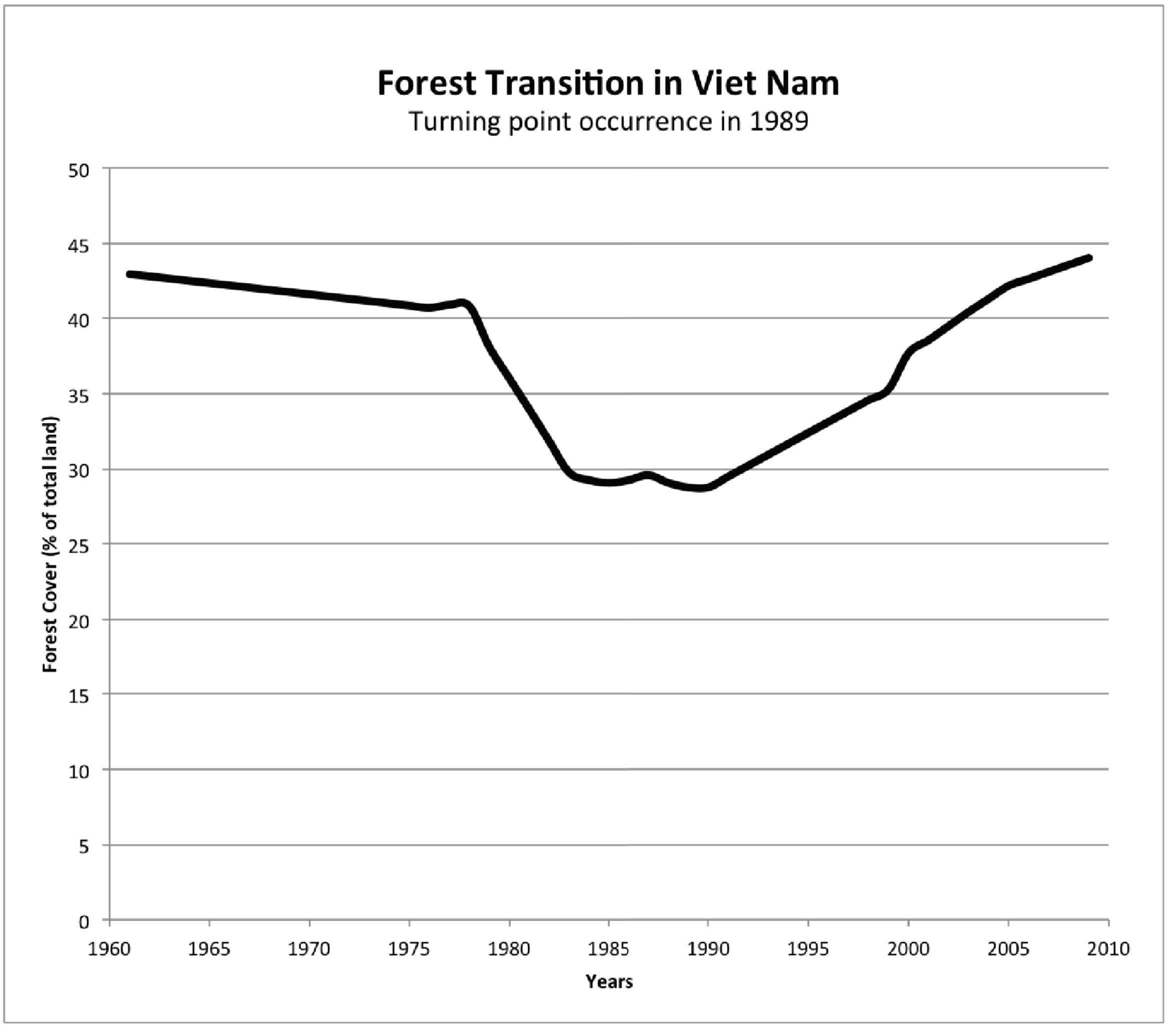
Table 5: Countries observing a turning point

Variable	Mean	Std. Dev.	Min.	Max.	N
Forest area	30.727	19.464	5.257	83.216	38
Agricultural area	46.914	20.895	9.66	85.465	38
GDPPC	6484.945	4623.285	941.844	22808.089	38
GDPG	5.372	3.735	-5.454	11.3	38
INST	7.395	4.309	2	14	38
POPDENS	135.614	123.365	11.883	497.037	38
POPG	1.141	0.743	-0.233	2.82	38
PAGR	0.108	0.149	0.004	0.571	38
IMPORTS	35.349	15.922	8.548	74.687	38
EXPORTS	31.308	14.325	7.134	73.568	38

Table 6: Countries still deforesting

Variable	Mean	Std. Dev.	Min.	Max.	N
Forest area	41.859	21.427	1.04	94.718	160
Agricultural area	36.295	18.599	0.462	83.995	160
GDPPC	3302.943	3127.018	117.227	15411.485	160
GDPG	3.444	6.488	-51.031	25.7	157
INST	7.994	3.298	2	14	160
POPDENS	82.406	156.334	1.719	1080.033	160
POPG	2.229	0.875	-1.501	4.906	160
PAGR	0.069	0.103	0.001	0.643	160
IMPORTS	37.587	17.762	4.631	100.597	157
EXPORTS	33.56	21.079	4.021	119.81	157

Appendix D. Time-series of forest cover in Viet Nam: an example of Forest Transition



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