Understanding the impact of timber plantations on tropical deforestation: a cross country analysis

Thomas Sembres
University of Cambridge
Department of Land Economy
19 Silver Street,
Cambridge CB3 9EP, UK
Tel: +44 1223 339773,
Fax: +44 1223 337130
E-mail:thomas.sembres@cantab.net

Dr. Andreas Kontoleon
University of Cambridge
Department of Land Economy
19 Silver Street,
Cambridge CB3 9EP, UK
Tel: +44 1223 339773,
Fax: +44 1223 337130
E-mail: ak219@cam.ac.uk

Dr. Claire Brown
UNEP-WCMC
219 Huntingdon Road
Cambridge, CB3 0DL, UK
Tel:+44 1223 277314
Fax:+44 1223 277136
E-mail:
Claire.Brown@unep-wcmc.org

Abstract

This paper shows that investing in timber plantations may have a positive or negative effect on tropical deforestation rates. We use a framework based on von Thünen's model of land use and conduct a cross-country data analysis of over 60 tropical countries to identify the conditions for a positive plantation effect on natural forests. We show that the effect of timber plantations on tropical deforestation cannot be anticipated without a concurrent assessment of the threat of conversion for agriculture. Understanding this interaction between timber plantations and agricultural rents is highly relevant for the swiftly emerging debate over REDD policies.

Key words: timber plantations, timber transition, agricultural rents, tropical deforestation, REDD

1. Introduction

The understanding of the significance of the threats from tropical deforestation for climate change, biodiversity conservation and ecosystem regulation have matured within policy circles. This has triggered a renewed and amplified interest in global policy endeavours to reduce tropical deforestation, which remains the largest source of biodiversity loss in the world and contributes to roughly a quarter of global greenhouse gas emissions (Houghton, 2005; MA, 2005). This is manifested most notably by recent developments in the post-Kyoto protocol deliberations that have important implications for tropical forests but also from significant developments in the deepening of the CBD commitments that resulted from the Conference of the Parties COP 9 meeting in May 2008. These deliberations have perhaps the most significant implications for tropical deforestation through the development of a mechanism to reduce greenhouse gas emissions from avoided deforestation and degradation (REDD).

One of the remaining challenges that threatens the success of REDD, however, is to thoroughly understand so called "targetable" factors associated with forest change, i.e. factors that can *realistically* be tackled by forest related policies. Focusing on such targetable factors is crucial if policies employed by tropical countries to reduce deforestation are to be effective. A significant body of the literature as well as actual policy work on tropical deforestation has concentrated on factors of forest change that have a low "targetability" (Kanninen *et al.*, 2007), such as population growth and density, standards of living (e.g. GDP), and other macroeconomic factors (e.g. interest rates). Evidently, controlling birth rates or accelerating urbanisation as a means of conserving forests would be both inapplicable and undesirable recommendations. Likewise, policies that focus on factors such as abandoning road expansion and investment in forest areas are often politically unfeasible as they are met with severe local opposition (Wunder, 2004). Hence, focusing on such factors would not translate easily into effective REDD policies. There is, thus, a need to focus further on more useful or pragmatic deforestation policies (Barbier, 2001).

This paper examines timber plantations as one such potentially important targetable factor affecting tropical forest change that has, nevertheless, been mostly neglected by the literature.[1] For example while examining the impact of fuelwood collection on tropical deforestation Köhlin and Parks (2001) note that it is surprising that "not much has been done to analyze the impact of plantations to reduce deforestation" (p.207). Indeed, there is some evidence that, in some contexts, timber plantations can remove the logging pressure from high conservation value forests, both at the local level (by shifting fuelwood collection) and the global level (by shifting the demand for roundwood and pulpwood) (Von Amsberg, 1994; Sedjo, 1999; Gullison, 2003; FAO, 2004). In other cases, however, the fact that plantations remove the timber pressure on natural forests does not translate eventually into less, but rather into *more* deforestation. Indeed, it is feared that agricultural expansion, which is the main cause of deforestation in the tropics, might replace forestry in the remaining natural forests (ITTO, 2002; Cossalter and Pye-Smith, 2003; MA, 2005). While forestry often only degrades the forest, agriculture is generally a wholesale land use conversion. The impact of timber plantations could, thus, turn out to be quite detrimental to tropical forest ecosystems (Kartodihardjo and Supriono, 2000).

Therefore, though it is acknowledged that timber plantations appear to be a relatively targetable driver of natural forest change[2], it may nevertheless not be easy to understand and predict its overall effect on natural forests. We can, thus, refer to this "ambivalent effect of timber plantations" as the fact that these plantations trigger both positive forces (which reduce deforestation) and negative feedback effects (which increase deforestation). In fact, this ambivalence is actually a widespread feature of many of the different drivers of deforestation (Kaimowitz and Angelsen, 2001). For instance, improvements in agricultural technology might on the one hand help to conserve natural forests (since higher agricultural yields may render marginal lands less attractive and eventually abandoned), but on the other, they may boost deforestation (as for example labour-saving technologies may push many landless peasants further into the forest). This tension between the “yield-increasing effect” and the “cost-saving effect” of improvements in agricultural technology has been well described by the literature (e.g. Angelsen and Kaimowitz, 2001). Similar ambivalent effects on tropical forest change have been documented for improvements in land tenure security (Angelsen, 2007), economic growth (Rudel *et al*., 2005; Ewers, 2006; Kanninen *et al*., 2007), population growth (Culas, 2007; Igliori, 2008), indebtedness (Kaimowitz and Angelsen, 2005) and oil wealth (Wunder, 2005). In this paper we attempt to shed some light on a similar two sword effect on tropical deforestation, namely that of timber plantations which we refer to as the “ambivalent effect of timber plantations”.

Further, the fact that single factors can both increase and reduce deforestation has led several authors such as Geist and Lambin (2001), Ewers (2006) and Fearnside (2007) to focus on *combinations* of factors, or *interaction effects* rather than on single drivers of deforestation. For example, Fearnside (2007) argues how rural outmigration to cities will not reduce pressure on forests in contexts where extensive ranching is profitable (such as in Brazil). Rather than rural exodus alone, it is the interaction between rural outmigration and land intensity of farming which matters for predicting impacts on deforestation. The effect of one factor of deforestation is therefore dependent upon the value of another variable.

In this paper we follow this recent acknowledgement that analysing interaction effects between factors is crucial for understanding deforestation trends. We describe this interaction of timber plantations with other key factors by using a conceptual framework based on von Thünen's model of land use as this provides a well-grounded and insightful approach for probing the problem at hand. On the basis of this framework we would expect timber plantations to increase deforestation where *agricultural rents* are high and independent from upstream logging, and having an opposite effect (and thus be beneficial for REDD) when agriculture is not generally a profitable endeavour.

We empirically explore this basic hypothesis using national level data from over 60 tropical countries. To our knowledge this is the first attempt to explain under which conditions timber plantations can have a positive impact on tropical forests at a national cross country scale. At the more localised level Köhlin and Parks (2001) identified that in the Indian state of Orissa the distance of the plantation to the village was a key factor to shift the collection of fuelwood from natural forests to the planted woodlot. Such existing work is valuable in understanding on-site substitution effects in fuelwood collection. We aim to complement and add to this work by undertaking a more macro-level analysis which should capture large-scale substitution effects in roundwood and pulpwood production (and not only fuelwood).

In sum, the paper provides several contributions to the tropical deforestation literature. First it focuses on the impacts of timber plantations as a highly targetable though widely neglected factor related to deforestation. Secondly, our work explicitly accounts for the ambivalent nature of this impact. Thirdly, it develops a conceptual framework that allows us to analyse the likely important synergistic effects between plantations and other key factors. Forth, it conducts a cross-country econometric large scale analysis of the problem at hand that complements and extends the more local site specific studies that characterise the existing literature. Our analysis also complements prospective models capturing the effect of international trade on timber prices and deforestation (e.g. Sohngen et al., 1997) by focusing on timber products that cannot be yet considered as global commodities. Lastly, our analysis provides valuable policy insights as it can help us to better predict the opportunities and threats of timber plantations in tropical countries within the newly emerging realities of the REDD system. Moreover, the conclusions should also interest biodiversity conservation supporters because timber plantations are viewed as a potential instrument to indirectly protect distant natural forests, and not simply as a tool to provide timber or sequestrate carbon.

In the next section we develop a comprehensive framework capturing the opposing effects of plantations on deforestation. We then focus on assessing the synergistic effects of timber plantations on natural tropical forests. In doing so, we use the von Thünen model of land use which allows us to identify *agricultural rents* as the key factor that interacts with timber plantations to jointly determine the final impact of additional plantations on tropical deforestation. We then present a purposefully assembled cross-country level data set that allows us to econometrically test the hypotheses derived from the conceptual framework (Sections 3 and 4). We conclude with policy implications from this work both in relation to REED and climate change but also with regard to biodiversity conservation (Section 5).

2. Conceptual framework for assessing the impact of timber plantations on deforestation

In this section we describe how the ambivalence of the timber plantation factor rests in a combination of opposing “substitution” and “price” effects. Further, we develop a conceptual framework based on the von Thünen model in order to show that the exact direction of this impact depends on how the timber plantations factor interacts or synergizes with agricultural rents.

2.1 Substitution and price effects of timber plantations

The *substitution effect* of timber plantations is perhaps the most broadly acknowledged of the two effects noted above. For example, a recent report by the World Resources Institute finds that "according to many experts, the need for further exploitation of natural forests could be greatly reduced by expanding production from industrial wood plantations" (WRI, 2001: 3). This effective substitution, in the timber market of wood from natural forests with planted timber has also been referred to as "timber transition", "offsetting effect" or even "compensatory effect". Over time, the sourcing of timber can massively shift from natural forests to productive plantations (Sedjo and Botkin, 1997; Sedjo, 1999; WRI, 2001; ITTO; 2002; MA, 2005). Timber plantations in the tropics increased almost four-fold between 1980 and 2000 (FAO, 2001) and there is widespread evidence that this transition is happening in a number of countries. Brazil, Zambia and Zimbabwe sourced, respectively, 62%, 50% and 50% of their industrial roundwood consumption from plantations in the last decade (FAO, 2001).[3]

Such findings have spread optimism amongst several authors on the beneficial role of plantations for halting the trends of tropical deforestation and biodiversity loss. For example, Sedjo and Botkin (1997) argue that "if tree planting and intensive management of a small area of forest can produce enough wood to meet the world's requirements, this could free large areas of natural forest from the pressure of timber harvests. The vast majority of remaining natural forests could consequently be devoted to non-timber uses, such as wildlife protection and habitat conservation…" (p.14). Strikingly, they estimate that less than 5% of the current forested area of the globe under intensive plantations would meet the world's demand for commodity-grade timber (used for pulp and construction). As to speciality-grade timber, which accounts for less than 10% of the world's demand for wood, it could be produced through specialised tree plantations or sustainably managed natural forests.

In other words, plantations could spare natural forests from logging activities without taking up much land. According to FAO (2004), Australian plantations only account for slightly more than one percent of the forest cover but contribute to 60 percent of national timber production. A hectare of planted forest is, on average, five to ten times more productive than a hectare of natural forest. Annual yields of timber per hectare are generally between $1m^3$ and $3m^3$ for managed semi-natural forests, while they range from between $5m^3$ and $40m^3$ for plantations of tropical species. Yields of up to 100 m^3 per year have been recorded in Brazilian trial plots (WRI, 2001).

It is important to note, however, that the replacement of natural forests by plantations as the main provider of timber is not a straightforward transition (WRI, 2001). A high plantation rate is not a sufficient condition to obtain the desired substitution effect. The successful case of New Zealand – where virtually all its timber production comes from plantations – has shown the importance of proactive supplementary policies that address most notably the need for adapting the existing wood processing facilities to the peculiarities of planted timber (e.g. logs of smaller diameter and lower density), the claims for compensation from private owners of natural forests, the consumers' reluctance to use fast-grown timber, etc. The need to take these issues into account explains why it took 70 years for New Zealand to end its timber transition.

Likewise, in the Brazilian state of Minas Gerais, supportive policies have proven crucial. Not only did the state subsidise the establishment of plantations for the provision of sustainable charcoal (in high demand from the iron production sector), but it also instituted both regulatory and fiscal disincentives for the exploitation of natural forests (Chomitz, 1999). By 1997, the charcoal production from native ecosystems had fallen by 80% compared to 1988, and the amount of deforestation had been dramatically reduced.

More importantly, though planted forests tend to reduce the pressure for timber on natural forests, this may not translate into less deforestation (Von Amsberg, 1994; Cossalter and Pye-Smith, 2003; Folmer and van Kooten, 2007; van Bodegom, et al. 2008). Indeed, in some contexts, it appears that agricultural expansion has benefited from fewer forestry activities in natural forests. This negative feedback effect can be explained in terms of a *price effect* of timber plantations.

In particular, the development of high-yield timber plantations is expected to depress, not only timber prices, but also the value of natural forests demarcated for production (i.e., outside protected areas). Cheap land can then attract extensive forms of agriculture and ranching (typically from cultivators living at the forest frontier) and large-scale agribusiness projects (e.g., oil palm plantation). According to the ITTO (2002), the decreasing value of commodity-grade timber (resulting from a new supply of cheap planted timber) will reduce the profitability of logging in natural forests (especially sustainable forest management - SFM) and this “plantation-induced loss of markets will simply magnify the pressure for conversion of the forests to industrial and/or subsistence agriculture” (p.22). Eventually, natural forests that were previously degraded by forestry may now be completely cleared by cultivators. The overall effect of timber plantations could thus be counterproductive for REDD and biodiversity conservation purposes.[4]

There is some evidence of such a negative price effect occurring in several contexts such as Brazil, where we find some of the most productive timber plantations in the world (WRI, 2001). Extractive reserves (i.e. large regulated areas managed by indigenous communities in the Amazon) are facing increasingly tough competition from plantations, not only in the markets for wood products, but also for non-timber forest products (NTFP), such as latex, oil, etc. (see Goeschl and Igliori 2006). Communities living in these reserves are becoming poorer and shrinking in size. In other words, competitive plantations elsewhere are threatening the very existence of the extractive reserves and are encouraging forest conversion outside the reserves, where the populations are now migrating. The potential social costs associated with this price effect are alarming. This Brazilian case also supports the ITTO's concern about the fact that sustainable forest activities (SFM, reduced impact logging, collection of non-timber forest products) are the first to suffer from the price effect, in advance of other, less sustainable, forestry enterprises.

The substitution and price effects, thus, combine into what we refer to as the ambivalent effect of timber plantations. Though this paper tries to assess the larger scale impacts of this ambivalent effect, there are other dynamics, which are generally more site-specific, that are worth referring to so as to better understand the impact of timber plantations on deforestation.

First, it is not possible to ignore that some timber plantations have had disastrous impacts on ecosystems locally, notably when they directly replaced native forests. Although some NGOs, such as the World Rainforest Movement, claim that the timber industry deliberately targets natural forests, it is often estimated that only 15% of all timber plantations in tropical countries have directly replaced closed-canopy natural forests[5], with great variations between countries. This share is estimated at 50% in Indonesia, but in Brazil, despite some well-known examples of destructive plantations (e.g. the Jari plantations in the state of Pará), the problem is quite limited at the national level.[6] According to Sedjo (1999) "although a common view is that plantations displace native forests, most forest plantations are actually established on former agricultural lands – (…) there are distinct advantages to locating plantations on degraded lands. These advantages include availability of roads, modest slopes, favourable location *vis à vis* markets, and so forth" (p.345). In addition, if plantations are found on land formerly covered by native forest, they may not be responsible for the initial clearing.

In other site specific cases, the labour-intensity of timber plantations also matters heavily to the impact on deforestation. If the plantations' business model is less labour-intensive than the previous land use, the shift may push people to migrate elsewhere and cause deforestation in their new settlement. This, for instance, has happened in Thailand (Carrere and Lohmann, 1996) while for the case of South Africa Cossalter and Pye-Smith (2003) calculated that the timber company MONDI generated just 1.1 jobs for every 100 hectares of plantation. Still, these are site-specific issues, which could be dealt with appropriate management and regulations. For instance, some countries (e.g. South Africa, India) have developed out-grower schemes (i.e., partnerships between companies and smallholders to produce timber without land acquisition from the company) which tend to give more employment opportunities lo local people (Cossalter and Pye-Smith, 2003).

Figure 1 attempts to summarise these different local and more regional dynamics that we have reviewed above. Along the vertical axis, the diagram shows that more plantations can lead to either an improved conservation of natural forests (substitution effect) or, conversely, to increased deforestation. The horizontal axis of Figure 1 specifies how each of the two opposite effects can operate both directly (i.e. where plantations are located, through local agents) and indirectly (i.e., through the market). This paper focuses only on large-scale indirect effects of plantations (and hence on quadrants 3 and 4 in Figure 1), which, arguably, have a higher impact on the national deforestation rate. The work by Köhlin and Parks (2001) mentioned above is an insightful study of on-site substitution effects (quadrant 1 in Figure 1), while other papers provide interesting recommendations to limit site-specific mismanagement of plantations which are characteristic of quadrant 2 (e.g. Chamshama and Nwonwu, 2004; Cossalter and Pye-Smith, 2004.).

[INSERT FIGURE ONE HERE]

Though Figure 1 captures the different opposing effects of timber plantations on natural forests it is nevertheless essentially descriptive in that it does not provide us with a framework for understanding the *mechanism* through which the substitution effect is likely to overcome the price effect. As argued in the introduction, a consensus is emerging in current deforestation literature of the need to assess the dynamics between combinatory factors or key interaction effects to predict such impacts on deforestation (e.g. Geist and Lambin, 2001; Ewers, 2006). Following this same approach, we now turn to explore how quadrants 3 and 4 in Figure 1 (the substitution and price effect) interact with other key factors, and "agricultural rents" in particular, to determine the ultimate direction of the impact of plantations on tropical forest deforestation.

2.2 Interaction effects between timber plantations and agricultural rents

As agricultural expansion and forestry activities are globally the main threats to tropical forests[7], we focus our analysis on the synergistic effects between timber plantations and agricultural rents as determining the overall outcome of the interplay between the substitution and price effects of timber plantations described in the previous section.

To explain how these synergistic effects emerge and impact on the deforestation rate we develop a conceptual framework based on von Thünen's model of land use change. Von

Thünen's location theory provides a well-grounded framework that has been acknowledged to be particularly useful for analysing tropical deforestation (e.g., von Amsberg, 1994; Hyde, 2005; Angelsen, 2007).[8] The basic premise of the model is that changes in land use correspond to changes in land rents, and that such rents decline with distance from the market. To set ideas we can consider a simple case with three possible uses of land competing with natural forests: timber plantations, agriculture, and conventional forestry (logging). More intensive land-uses (plantations and agriculture) are located closer to the city than extensive ones (forestry) because of declining land prices with distance. Deforestation happens when the furthest land use expands into the natural forest. In our example, conventional forestry is the most remote land use and is therefore responsible for deforestation, but, because we can argue that loggers often only degrade the forest, the frontier of agricultural activities also matters for deforestation.

Figures 2 and 3 capture this conceptual framework and displays land rents curves declining with distance for two different regions. Focusing first on Figure 2, we observe that the agriculture rent curve lies above the others, but only at relatively close distance from the city. Following logic in the von Thünen's framework, agriculture is mapped as the dominant land use close to the market centre, but then replaced by forestry in more remote areas. There are no timber plantations in the landscape of Figure 2 as potential rents from this business are not competitive with other land uses at any distance from the centre. The only difference between the two regions is the profitability of agriculture (curve 2 in Figure 2). Agriculture is not very attractive in region 1 (e.g. Gabon), whereas it yields high returns in region 2 (e.g. Brazil). Accordingly, Figure 2 displays a steeper agriculture rent curve in region 1 (i.e., rents exhaust rapidly with distance from the market) compared to region 2.

INSERT FIGURE 2 HERE

At this point in time (T_0) in Figure 2, both regions undergo deforestation because of positive rents in the forestry sector, even in the most remote areas. Region 2 has more forest conversion to cropland than region 1, but the bulk of the deforestation (and forest degradation) is due to forestry in this example.

At a later period (T_1), following effective government policies to encourage timber plantations (e.g. as a side effect of Kyoto implementation policies) we would observe the bid-rent curve of plantations to rise significantly. As a result, planted timber is now grown in both regions. The boom in timber supply from plantations might also lead to a decline in timber prices (assuming that the boom more than offsets the potential increase in demand for timber over the period and that planted timber is effectively a substitute for 'natural' timber[9]), which eventually hampers the profitability of forestry in natural forests. Higher profits in the plantations sector and fewer rents in traditional forestry are represented by the shifting bid-rent curves 1 and 3 in Figure 3.

INSERT FIGURE 3 HERE

In region 1 of Figure 3, the fall in the forestry rent curve below the horizontal axis entails that all profit making opportunities in these remote areas have been exhausted. Conventional logging withdraws from these distant forests and natural forest is allowed to regenerate. In region 2, however, the withdrawal of forestry from distant forests does not mean that opportunities of profit from other activities are absent: there is much scope for agricultural expansion. These two cases, thus, show how growing timber plantations can have opposite effects on natural forests, depending on the nature of the interactions between timber plantations and agricultural rents.

On the basis of this framework we posit our main hypothesis that asks whether in fact we actually observe in tropical settings an acceleration of deforestation and degradation when plantations interact with high agricultural rents, and conversely when these rents are low. Given the very limited availability of data on timber plantations in tropical settings, a testable hypothesis is to frame things at the national level (it is also the most convenient level for making REDD recommendations)[10]. The remaining of this paper, therefore, is an attempt to examine whether tropical countries tend to show patterns as those depicted in regions 1 and 2 in Figure 3. We call type-1 countries those where deforestation is mainly driven by forestry activities (and are associated with low agricultural rents) and type-2 countries those where agriculture is by itself a serious threat to natural forests (high agricultural rents). Expressed differently, all else being held constant, growth in the supply of planted timber (ΔPL) is expected to impact the national deforestation rate of natural forests (ΔNF) as follows:

$$\Delta NF = \alpha + \beta . \Delta PL \qquad (1)$$

The parameter β corresponds to what was called the ambivalent effect of timber plantations and captures, alternatively, the substitution effect, expected in type-1 countries ($\beta > 0$), or the price effect, expected in type-2 countries ($\beta < 0$). Type 1 countries should exhibit a positive β implying that in those contexts more planted timber would lead to less deforestation (the deforestation rate ΔNF gets closer to zero, as timber increasingly comes from plantations rather than from natural forests, which reduces the amount of new logging roads and so forth). Type 2 countries that would have a negative β would imply that more plantations translates into additional deforestation (the deforestation rate ΔNF deepens, as the withdrawal of forestry from natural forests suddenly makes, for instance, oil palm cultivation the most attractive land use). The intercept α captures the effect of other factors affecting deforestation (and kept constant here).

3. Empirical model building

Following the approach in other cross sectional data analysis of deforestation (e.g. Barbier, 2001; Ewers, 2006) we proceeded with assembling a data set that would enable us to distinguish the different effects of β between type-1 and type-2 countries.[11] Since such suitable data is neither readily available nor usable in its raw format we detail here the steps and assumptions made for assembling it.

First, with respect to our dependent variable we made use of FAO's data on deforestation in tropical countries, as it is the only source of comparable and consistent data over broad space and time scales. It would have been preferable to use more robust GIS data such as that provided by the World Resources Institute (WRI)[12], but this was not available for more than one year (in the case for the WRI data it was for the year 2000 only). We made use of FAO's 2005 Global Forest Resources Assessment and obtained deforestation rate data for the period 2000-2005.[13]

We then had to develop a meaningful and robust classification of type 1 and 2 countries so that to be able to test for changes in β across country type. This was accomplished through qualitative and quantitative sources of information obtained from open access on-line sources as well as from sources from the World Conservation Monitoring Centre (WCMC) in

Cambridge England.[14] The time period we managed to assemble consistent and complete data was 1990-2005.[15] This information made it possible to identify a set of countries where forestry (including all forms of forestry from the large-scale pulpwood industry to household-level collection of fuelwood) was unequivocally the main driver of deforestation without much competition from agricultural expansion. These were classified as type-1 countries. Likewise, type-2 tropical forest countries were identified as those where agricultural expansion (including subsistence and commercial agriculture, ranching and biofuel crops) was the overwhelming cause of deforestation.

However, for many tropical countries, this binary categorisation was not satisfactory. Land use pressures are often numerous and dramatically inter-related to each other. Forested lands in Ghana, for instance, are threatened simultaneously by shifting cultivation, uncontrolled logging, surface mining and charcoal production (UNEP, 2008). Furthermore, in many parts of the tropical world, logging and agriculture cannot be assessed separately as the former is the catalyst of the latter. Indeed, according to Barbier (1994), who assessed six West African countries, agriculture expansion barely takes place outside areas previously logged by foresters, because peasants rely on logging roads to transport their agricultural surplus to the market and find it easier to cultivate on lands where the larger trees have already been removed, with debris available for burning, etc. In the Democratic Republic of Congo, however, logging is generally not followed by agricultural conversion because it takes place in very remote forest areas where population density is low (Laporte *et al.*, 2007).

The reality of the relationship between forestry and agriculture is, thus, complex, highly context-specific. Loggers opening up forests often enhance potential agricultural rents, but, on the other hand, their concession rights spanning over several decades sometimes act as a barrier against further agricultural expansion into the forest domain. This last argument might explain the fact that some prominent NGOs have supported the recent allocation of forest concessions in the Brazilian Amazon (Karsenty *et al.*, 2008). In the Democratic Republic of Congo, Laporte *et al*. (2007) argue that logging concessions are becoming a defence option against the predicted future demand for large-scale conversion to palm oil. A third group of countries, therefore, was identified (type-3) to account for cases where agriculture relies (i.e. is endogenous) on forestry for its encroachment on the forest. Countries where the sequence predominantly happens the other way round (i.e. initial clearing for agriculture and then timber is sold as a by-product), were considered as a type-2 countries.

Table 1 summarises how the three types of countries were identified as well as the likely sign of the β parameter in Eq. (1). So for example countries such a Gabon where logging in natural forests is generally not followed by agriculture where classified as type 1, countries such as Brazil where agricultural rents are high and mostly exogenously determined from logging were classified as type-2, and countries such as Sierra Leone where agricultural rents are mostly dependent on upstream logging as type 3.

INSERT TABLE 1 HERE

The following step in assembling the data and building our empirical model was to collect suitable data on timber plantations. Ideally, commodity data on timber should be used rather than land use data on plantations as the quantity of timber in the market is what matters for the substitution and price effects. More intensively managed plantations could have the same impact as a greater number of plantations. However, data on the provenance of timber is not available in most developing countries.

Because of these difficulties with different timber plantation data it was decided to use instead a more robust dummy variable proxy to capture the occurrence of a timber transition. For a timber transition to occur (followed by a substitution or price effect), it was considered that the establishment rate of timber plantations shall be at least equal to a gain of 1 to 3 hectares per 1000 inhabitants over the previous decade[16]. These are fairly low thresholds (a timber transition may need more substantial and quicker increases), but, arguably, when FAO reports an increase of one hectare of plantations per 1000 inhabitants, it is probably an underestimate of the actual situation on the ground (as a sizeable proportion of planted timber comes from trees outside forests such as micro-plantations in cities, on farms, along roads, etc.). Moreover, given that new timber plantations in the 1990s tend to be much more productive than previous establishments, a timber transition may well be set in motion by relatively small increases in the area of plantation per capita (the per capita element is important to capture, however imperfectly, the increase in wood demand).

Another promising avenue would have been to use country-specific time lags for capturing the effect of timber plantations on the national deforestation rate. Indeed, each tropical country has its own peculiar species mix of planted trees. Trees planted in 1990 in Brazil may provide large amounts of timber as soon as 1997 and affect forestry in the Amazon basin soon after, whereas those planted the same year in Ghana may be massively harvested only after 2010. Again, because of limited data availability on timber plantations, a simplistic choice was made and we ultimately tested the effect of trees planted in the 1990s on the 2000-2005 deforestation rates. This choice is nonetheless comforted by the fact that there has been an increasing homogenisation of new plantations in the tropics in the last couple of decades towards a handful of fast-growth species such as eucalyptus and pine trees (Cossalter and Pye-Smith, 2003).

Finally, needless to say, the lack of reliable data on essential control variables (road building in forested areas, transport costs, land tenure security, etc.) adds to the challenge of building a suitable database on deforestation in tropical countries.[17] The results presented in the next section should then be considered in the light of the limits of a cross-country analysis consisting of only 61 observations. These difficulties in assembling such a dataset are certainly one of the reasons why we have not seen research in this area. As such, this study that uses 'second-best' data is a first preliminary attempt to explore the impacts of timber plantations on tropical deforestation at a large scale level of analysis.

4. Results

The data described in the previous section gave rise to the following basic specification for testing the timber plantations' ambivalent effect[18]:

$$\Delta NF = \alpha + \beta_1 T + \beta_2 A + \beta_3 TT + \beta_4 TT.T + \beta_5 TT.A + \beta_6 Z + \varepsilon \qquad (2)$$

where, ΔNF is the 2000-2005 annual natural forest change rate (deforestation rate); α is the constant intercept term; T and A are dummy variables for 'timber-driven deforestation' countries (i.e., type-1 countries) and 'agriculture-driven deforestation' countries (i.e., type-2 countries) respectively (the type-3 category served as the omitted category in the regression); TT stands for 'timber transition'; TT.T and TT.A are the respective interaction terms (they refer to the crucial interaction effect); Z captures other important explanatory variables described in Table 2 and ε is the error term.

INSERT TABLE 2 HERE

In equation (2), when ΔNF increases, deforestation is reduced. Hence, coefficients β_1 and β_2 should be positive, as deforestation in these countries should be lower than in countries of the omitted category (i.e., type-3 countries characterised by high pressures from both agriculture and forestry). More importantly, we expect β_3 to be positive because it captures the effect of a timber transition in type-3 countries[19]. In these countries, if planted timber can spell doom to forestry in natural forests, it should also deter further agricultural expansion (endogenous agricultural rents from logging). The net effect of timber plantations in type-1 countries is given by the sum of $\beta_3 + \beta_4$, which we expect to be positive (low agricultural rents in type-1 countries in Figure 3). In type-2 countries, however, a timber transition is likely to accelerate deforestation through increased agricultural conversion, hence an expected negative sign for $\beta_3 + \beta_5$. The expected sign of the other coefficients is positive for corruption control, negative for population growth, but less clear, and of less importance here, for the other control variables.

The results of the regression analysis, (performed using STATA), are presented in Table 3. The robustness of the interaction terms was checked by testing for multi-collinearity between TT, A and T. The dataset for the 61 countries and was almost balanced[20]. Moreover, it should be emphasised that different intensities of 'timber transition' were tested, in order to check whether ambitious plantation programmes have a stronger impact on deforestation rates than smaller experiences. In particular three TT variables were defined, TT1, TT2, and TT3 depending on whether a country that experienced a timber transition had a gain of at least one, two, or three hectare respectively of timber plantation per thousand inhabitants between 1990 and 2000.

INSERT TABLE 3 HERE

The first regression (TT1) in Table 3 exhibits results that are all reasonably statistically significant (except for the GDP growth variable), displays the expected signs for the coefficients and has a relatively high adjusted R-squared. The results for the three levels of timber transition support the hypothesis that agricultural rents (captured by the country's type variable) determine where timber plantations are helpful and, conversely, where they are counterproductive, for reducing deforestation. For instance, taking TT1 into consideration, a timber transition is expected to *increase* the deforestation rate by 0.53 percentage point in 'agriculture-type' countries (type-2), whereas it would *reduce* this rate by 0.15 percentage point in 'timber-type' countries (type-1). These estimates are calculated by adding the TT coefficient with the TT_A or TT_T coefficient given in Table 3. A look at the omitted category (type-3 countries) also supports the hypothesized story presented in Table 1: a timber transition in type-3 countries is expected to reduce deforestation even more so than in type-1 countries, because it acts as a deterrent for logging and subsequent agricultural expansion.

Furthermore, on examining the change in the coefficients between the three specifications in Table 3, it seems that a more sizeable timber transition (i.e. TT3 relates to a more important timber transition than TT1) reinforces these opposite effects in type-1 and type-2 countries (though not for type-3 countries).[21] We see that TT3 is expected to reduce the deforestation rate by 0.31 percentage point in 'timber-type' countries and to increase it by 0.55 percentage point in 'agriculture-type' countries. Given that a typical tropical country exhibited a deforestation rate of slightly less than 1% per annum in 2000-2005, these marginal changes appear as very substantial. Figure 4 summarises these trends, showing that the deforestation rate gets closer to zero in type-1 countries with higher levels of timber transition, whereas, in type-2 countries, deforestation deteriorates towards a rate of more than 1.2% per year. These numbers are provided so as to provide a qualitative insight of this ambivalent effect of timber plantations across a large scale and not as a robust indication of the exact magnitude of this effect.

INSERT FIGURE 4 HERE

Figure 4 based on the results of this very basic cross-country analysis suggests that timber plantations impact significantly on the deforestation rate in tropical countries and this impact can be either positive (substitution effect) or negative (price effect). The discrepancy between the two effects seems to be sizeable enough to conclude that understanding the effect of timber plantations is crucial from a REDD perspective. Risks involved in countries where deforestation is mainly driven by agricultural expansion appear to be substantially higher than the REDD benefits obtained in "timber-driven deforestation" countries (as shown by the steeper slope of the downward curve compared to the upward curve in Figure 4). This lends strong justification to adopt a precautionary approach with timber plantations when the relationship between forestry and agriculture is not well understood.

Although it is not the focus of this study, Table 3 also shows that institutional variables (notably corruption control) tends to impact heavily on the deforestation rate, at least more than population growth[22] and GDP growth[23]. This result is consistent with the findings of Culas (2007) and an earlier paper by Bhattarai and Hammig (2001), who stated that "underlying institutional factors are relatively more important for explaining the tropical deforestation process than other frequently cited factors like population and macroeconomic conditions" (p.106).

5. Discussion.

In this paper we undertake the first large scale cross country analysis of the impacts of the ambivalent effect of timber plantations on tropical deforestation as an attempt to complement existing related work that has focused on local site specific studies and data. Any large scale modelling of this ambivalent effect is limited by serious data availability and consistency issues (detailed above) which hinder a more comprehensive general equilibrium or international trade modelling approach. We nevertheless attempted to assemble a coherent and usable data set which lent itself to be used for a first attempt at a cross country econometric analysis of this ambivalent effect. Despite the limitations of our analysis (stemming from unavoidable data limitations and restrictive specification assumptions) our basic modelling approach did provide unique, novel and clear qualitative insights and trends. Hence, though our results should be considered with these caveats in mind they can certainly be a useful baseline starting point for future research on the large scale effects of timber plantations on deforestation rates.

The empirical results of the cross-country analysis tend to lend support to the conjecture derived from the von Thünen framework discussed in Section 2 that the *interaction* between timber plantations and agricultural rents determine deforestation rates in tropical countries. The analysis shows that it is, thus, crucial to know whether agricultural rents are either low, high and exogenous, or if they are high but endogenous (to upstream logging), in order to predict the effect of a plantation programme on deforestation in a given tropical country. Timber plantations, therefore, are expected to substantially impact on the deforestation rate in distant natural ecosystems, increasing it in countries where deforestation is mainly driven by the demand for agricultural land (high and exogenous rents), but reducing it in others. Furthermore, the results are probably underestimating the overall impact of plantations on natural forests since *degradation* was overlooked in our analysis (as only data on *deforestation* was available).[24]

An interesting implication of these preliminary findings is that timber plantations could have their highest positive effect on natural forests in countries where agricultural rents are endogenous to upstream logging activities. As explained above, this relates to the fact that, in many countries, timber extraction and agricultural expansion are often characterised by a *dependency* rather than *competitive* relationship with each other. Agricultural expansion into forest could suffer more from the weakening of forestry in natural forests than benefit from it, as assumed in the conceptual analysis in Section 2 where we did not consider type-3 countries.

Taking this finding into consideration, some policy recommendations can be made. First, the effect of timber plantations on tropical deforestation cannot be understood without a concurrent assessment of the threat of conversion for agriculture. We have seen evidence that a boom in the plantation sector is able to deter logging activities in natural forests (substitution effect). It is important to then ask what will subsequently happen when forestry withdraws from natural forests. Which of the two main alternatives to forest management in tropical forests, namely natural regeneration or conversion to agriculture, will prevail and where? In addressing such key questions what is crucial is to understand the role of forestry *in relation to* the agricultural sector. Our analysis suggests that synergetic driver combinations, rather than single variables, are most useful to explain tropical deforestation. This implication is in line with the findings from the more general meta-analyses studies on deforestation (e.g. Geist and Lambin, 2001).

Further, our paper proposes a framework to broadly anticipate the impact of timber plantations on the basis of three different situations. In the first case, in locations where forestry is the only major threat to natural forests (low agricultural rents), timber plantations should help to reduce deforestation (substitution effect prevails). In other contexts, however, where forestry is a competitor to agriculture at the forest frontier (high exogenous agricultural rents), timber plantations risk increasing the rate of deforestation (price effect prevails). In a third case, where forestry is a facilitator of agricultural expansion at the forest frontier (high but endogenous agricultural rents), timber plantations have again a high potential to reduce deforestation.

We acknowledge of course that many situations do not easily fit within this simple categorisation. For instance, in Malawi where fuelwood is in high demand from tobacco producers, timber plantations may foster tobacco cultivation rather than reduce the need to log natural forest for timber (UNEP 2008). In other situations, where forestry is absent from the forest frontier, none of these scenarios should be relevant. Furthermore, the national scale (confounded within a single country jurisdiction) may not always be the suitable level for exploring the full beneficial potential of timber plantations. A more localised and coherent level (the watershed unit, for instance) may be more relevant in certain cases, whereas, in others, policies on timber plantations might have to take international trade issues into consideration (Sedjo, 1999).

Finally, with respect to long-term implications, it should be reminded that within any jurisdiction timber plantation developers should by no means be given a "*carte blanche*". Instead, adequate dealing with social concerns (e.g. providing employment alternative opportunities, avoiding land tenure conflicts and decline in agricultural supplies) as well as environmental issues (maintaining ecosystem services, especially watershed services) is essential to an effective REDD plantation policy in the long-term.

In sum, timber plantations can be a potentially beneficial REDD and biodiversity conservation strategy in cases where the natural forest is threatened by forestry alone (a not so common situation in the tropics), or when agricultural expansion is heavily dependent on the pursuit of logging by foresters (opening new roads, etc.). Moreover, previous successful experiences (e.g., New Zealand, Minas Gerais in Brazil) have shown that public policies, and not only market forces, are key to the success of a REDD-friendly and locally sustainable timber transition. All in all, it appears that only under limited conditions can timber plantations become a useful strategy to reduce tropical deforestation, which is a valuable insight for both climate stabilisation and biodiversity conservation efforts.

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Table 1: Classification by country type and expected sign of the plantation parameter

Country's type		Description	Agricultural rents at the forest frontier	Expected effect of reducing logging (through the plantation effect, or a logging ban)	Prevailing timber plantation effect	Expected sign of coef. β in eq. (1)	Expected recommendation with timber plantations
Type 1	Timber-driven deforestation	Forestry alone is the major threat to forests	**Low**	Reducing logging in natural forests would limit deforestation and degradation	**Substitution effect**	Positive	Support timber plantations to reduce logging in natural forests
Type 2	Agriculture-driven deforestation	Agriculture is essentially the main driver of deforestation (with or without upstream logging operations)	**High and exogenous** (not dependent on upstream logging)	Reducing logging would make forests even more at risk of wholesale clearance by agriculture	**Price effect**	Negative	Avoid ambitious timber plantation programmes (rather favour SFM and protected areas)
Type 3	Timber-then-agriculture driven deforestation	Logging is a necessary catalyst to agricultural conversion	**High but endogenous** (dependent on upstream logging)	Reducing logging would slow down the whole process of forest degradation followed by agricultural conversion	**Substitution effect +**	Highly positive	Support timber plantations to reduce logging followed by conversion to agriculture

Table 2: Summary statistics

Variable	Name	Source	Obs.	Mean	Std.Dev.	Min.	Max.
NF	Natural forest change 2000-2005 (ann.%)	FRA 2005 (FAO)	61	-0,85	1,32	-6,8	1,3
TT	Timber Transition (1990-2000)	FRA 2005 & World Bank	61	0,38	-	0	1
T	Country Type 1 (timber)	UNEP (2008); etc.	61	0,49	-	0	1
A	Country Type 2 (agriculture)	UNEP (2008), etc.	61	0,21	-	0	1
TA	Country Type 3 (timber-agriculture)	UNEP (2008), etc.	61	0,30	-	0	1
TT_T	Occurrence of TT1 in type-1 countries	calc.	61	0,18	-	0	1
TT_A	Occurrence of TT1 in types-2 countries	calc.	61	0,08	-	0	1
CORRUPC	Corruption Control	World Bank	61	-0,53	0,51	-1,4	1,1
POPG	Population growth in the 1980s (ann.%)	World Bank	61	2,58	0,94	-0,4	4,8
GDPG	GDP growth 1999-2004 (annual %)	World Bank	61	3,80	2,90	-4,4	13,9
EXPORT	Exports as % of GDP (1999-2003)	World Bank	61	34,19	23,30	7,5	118
SMALLI	Small island country	-	61	0,10	-	0	1
SEASIA	South East Asian country	-	61	0,16	-	0	1

Table 3: Econometric results

	Regression 1		Regression 2		Regression 3	
	TT1		**TT2**		**TT3**	
TT	1.49	*** (3.05)	1.23	** (2.42)	0.70	(1.54)
T (type-1 country)	1.80	*** (4.49)	1.61	*** (4.04)	1.33	*** (3.50)
A (type-2 country)	1.44	*** (2.92)	1.25	** (2.51)	0.97	* (1.99)
TT_T	-1.34	** (-2.17)	-1.08	* (-1.69)	-0.39	(-0.73)
TT_A	-2.02	** (-2.66)	-1.76	** (-2.23)	-1.25	(-1.60)
CORRUPC	0.96	*** (3.63)	0.89	*** (3.30)	0.85	*** (3.04)
POPG	-0.33	* (-1.94)	-0.35	* (-1.95)	-0.37	* (-2.00)
GDPG	0.05	(1.07)	0.04	(0.86)	0.03	(0.60)
EXPORT	0.01	* (1.92)	0.01	** (2.01)	0.01	* (1.87)
SMALLI	-1.80	*** (-3.31)	-1.85	*** (-3.31)	-1.90	*** (-3.28)
SEASIA	-0.98	*** (-2.34)	-0.97	** (-2.26)	-0.86	* (-1.94)
Constant	-1.11	* (-1.69)	-0.92	(-1.37)	-0.55	(-0.83)
Obs.	61		61		61	
F(11, 49)	5.34		4.76		4.18	
Prob > F	0.00		0.00		0.00	
R-squared	0.55		0.52		0.48	
Adj R-squared	0.44		0.41		0.37	
Variance Inflated Factor	2.10					

Results for 61 tropical countries

Dependent variable: natural forest change 2000-2005 (annual %)

t-value in parenthesis ***Significant at 0.01 level; **significant at 0.05 level; *significant at 0.10 level.

Figure 1: Impacts of timber plantations on natural forests

Figure 2: A von Thünen's representation of land uses at $T_{0,}$ (with no timber plantations)

Figure 3: A von Thünen's representation of land use changes at T_1, after a surge of timber plantations

Figure 4: Net impact of timber plantations on deforestation in type 1 and 2 countries

[1] In this paper we focus on productive plantations, or "timber plantations", as opposed to protective plantations. The former are grown *primarily* to provide timber products (roundwood, pulpwood, fuelwood, charcoal), whereas the latter aim to provide environmental services (watershed services, carbon storage, ecosystem regeneration, etc.).

[2] There are, nevertheless, various unresolved issues associated with policies promoting sustainable timber plantations. For example, many African countries (e.g., Kenya) have now less timber plantations than a few decades ago because of poor management issues. Also, the survival rate of trees in plantation in West Africa is often quite at around 50% (Chamshama and Nwonwu, 2004). Another problem is that many plantations initiatives have failed to deal adequately with soil and water issues, the displacement of local people and with ensuring that plantations do not replace native forests in the first place.

[3] The occurrence of a timber transition is quite straightforward to detect when data on the provenance of timber is available, such as in Brazil for which evidence suggests that timber extracted from natural forests has been decreasing in absolute terms since 1990, progressively replaced by competitive planted timber (Bacha 2006). As Rudel *et al.* (2005) explain, reforestation is a predictable outcome in countries where wood products have become too scarce (e.g., India), but Brazil proves that a timber transition can also occur in countries with abundant natural forest.

[4] Bowyer *et al*. (2005) based on the work by Lovejoy (1990) draw an interesting parallel between this negative price effect of plantation and the impact of a boycott on tropical timber. They argue how the lower timber demand resulting from a boycott on tropical timber would reduce the value of forested land, making conversion to cropland or pasture more likely.

[5] This estimate is found in several papers but the original study dates back to Postel and Heise (1988). It should be reminded here that tree crops, such as oil palm and rubber, are not counted in the official forest plantation category (such as in FAO data), although they increasingly provide timber and fibre to the market (as by-products). The FAO is considering changing its definition of forest plantation in the near future.

[6] Grieg-Gran (2006) found that tree plantations in Brazil country occupy less than one percent of the annually deforested area.

[7] Mining, infrastructures, urbanisation, wildfires and hydroelectric projects can also cause important deforestation in some countries, but they rarely influence *national* deforestation rates more than agriculture and forestry.

[8] As any economic model, the von Thünen's perspective is based upon a set of simplifying assumptions such as significant transport costs, production being significantly tied to central markets and no conversion costs between alternative land-uses. See Angelsen (2007) for a critical review of these assumptions. Despite its limitations, the von Thünen framework does have considerable explanatory power to help formulate our econometric specification.

[9] According to Sedjo and Botkin (1997), more than 90% of the world's demand for timber is for commodity-grade wood, for the production of which plantations are perfectly suited. A portion of speciality-grade wood can also be grown on plantations (e.g., teak in Thailand, mahogany in Fiji).

[10] Broad cross-country studies on tropical deforestation have nonetheless been criticised for their use of very poor quality data (Kaimowitz & Angelsen, 2005, Scrieciu, 2007) and the trend is to focus on more localised dynamics, at the level of the different deforestation agents (Barbier, 2001). However, since the effect of timber plantations on deforestation partly relies on the occurrence of a price effect, overly localised units of analysis would be inappropriate. Due to its relative economic homogeneity (tax system, trade barriers, transport costs, agricultural policy, *etc.*), the national scale often remains the most relevant for timber prices and deforestation rates (Rudel and Roper, 1997).

[11] It should be noted that though this type of analysis is attractive for its simplicity, a more comprehensive general equilibrium model could be developed to take into account, notably, trade implications on timber prices (see for instance Sohngen et al., 1997) and elasticity of timber demand (von Amsberg, 1994). The added value of this type of modelling is likely to increase in the future, as timber products increasingly become a global commodity. However, for the period (1990-2005) and the regions considered here, timber prices were quite independent from global markets (91% of the harvested wood volumes in tropical Africa are still consumed domestically as fuelwood and, even in Brazil, the interior market absorbs the bulk of the national timber production).

[12] Global Land Cover Facility (GLCF) accessed at http://glcf.umiacs.umd.edu/data/.

[13] "For many governments, 'forest' denotes a legal classification of areas that may or may not actually have tree cover." (MA, 2005: 590). Hence, in order to avoid studying 'forests without trees' the rule adopted here was to reject those countries where the FAO forest area data was 25% larger or more than the WRI data (e.g. Niger).

[14] We used reports such as the 2008 UNEP Atlas on Africa, and the report by Grieg-Gran (2006) providing percentage estimates of deforested area by land use and by country to make an initial classification. Specialised

literature on deforestation in specific countries was also exploited (e.g., Lang, 2001; Grau, Gasparri and Aide, 2005; Silva-Chavez, 2005; Wunder, 2005; Chomitz, 2007). We then examined indicators, such as the annual agricultural expansion in percentage of the total forest area and the annual roundwood production per hectare of standing forest, to corroborate the qualitative sources of information and available expert knowledge at the WCMC.

[15] It should be noted that this classification could be sensitive to the time period of the data. Future work could explore how our results change when consistent data is made available for longer time periods.

[16] A redefinition of FAO's plantation category was made, (1) by adding the data on "planted semi-natural forests" (subtracted from the FAO "natural forest" category), and (2) by subtracting the data on protective plantations (i.e., those not providing timber to the market).

[17] Even widely used measures, such as GDP, are lacking for some countries (Somalia, Myanmar and Cuba, for instance), which were thus discarded from the analysis.

[18] A panel data analysis was considered in order to increase the sample size, but, because of the lag effect of timber plantations on deforestation, and because of unreliable forest data before 1990, this option was untenable. A possible option, however, was to use yielding growth rate variables in order to assess the effect of marginal changes on the deforestation rate: timber transition calculated from increases in timber plantations in 1990s, population growth rate for 1980-1990, GDP growth rate, etc.

[19] Because the dummy variable corresponding to type-3 countries is used as the omitted category in the regression, the coefficient corresponding to a timber transition in these countries is simply equal to the TT coefficient.

[20] After elimination of the countries with data problems (according to the rules explained in section 3), the final dataset had only three missing observations, which were estimated by fitting a trend to previous observations.

[21] This is not a consistent result, and as discussed in the conclusion, it reminds us that this econometric model is very simple and uses second-best data. The results are therefore rather indicative of the existence of the opposing timber plantations' effects than a definitive assessment of the scale of these effects.

[22] See the coefficients in Table 3, and the range and standard deviation of the two variables in Table 2.

[23] GDP growth has the weakest p-value in Table 3. An attempt was made to replace GDP growth with GDP and GDP squared, to test for the EKC hypothesis, but it did not prove significant.

[24] According to the IPCC (2007), forest degradation contributes more to Sub-Saharan greenhouse gas emissions than deforestation.

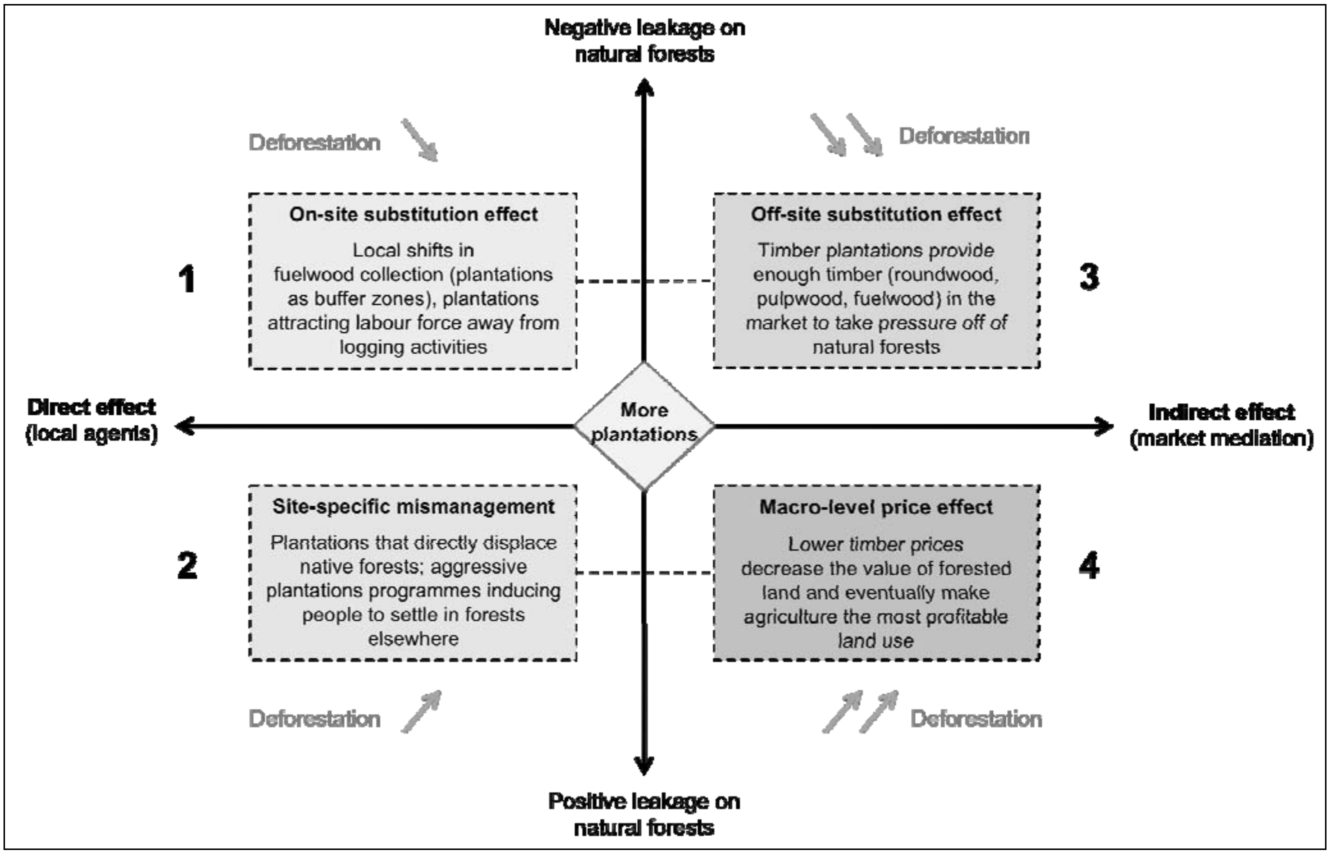

Figure 1: Impacts of timber plantations on natural forests

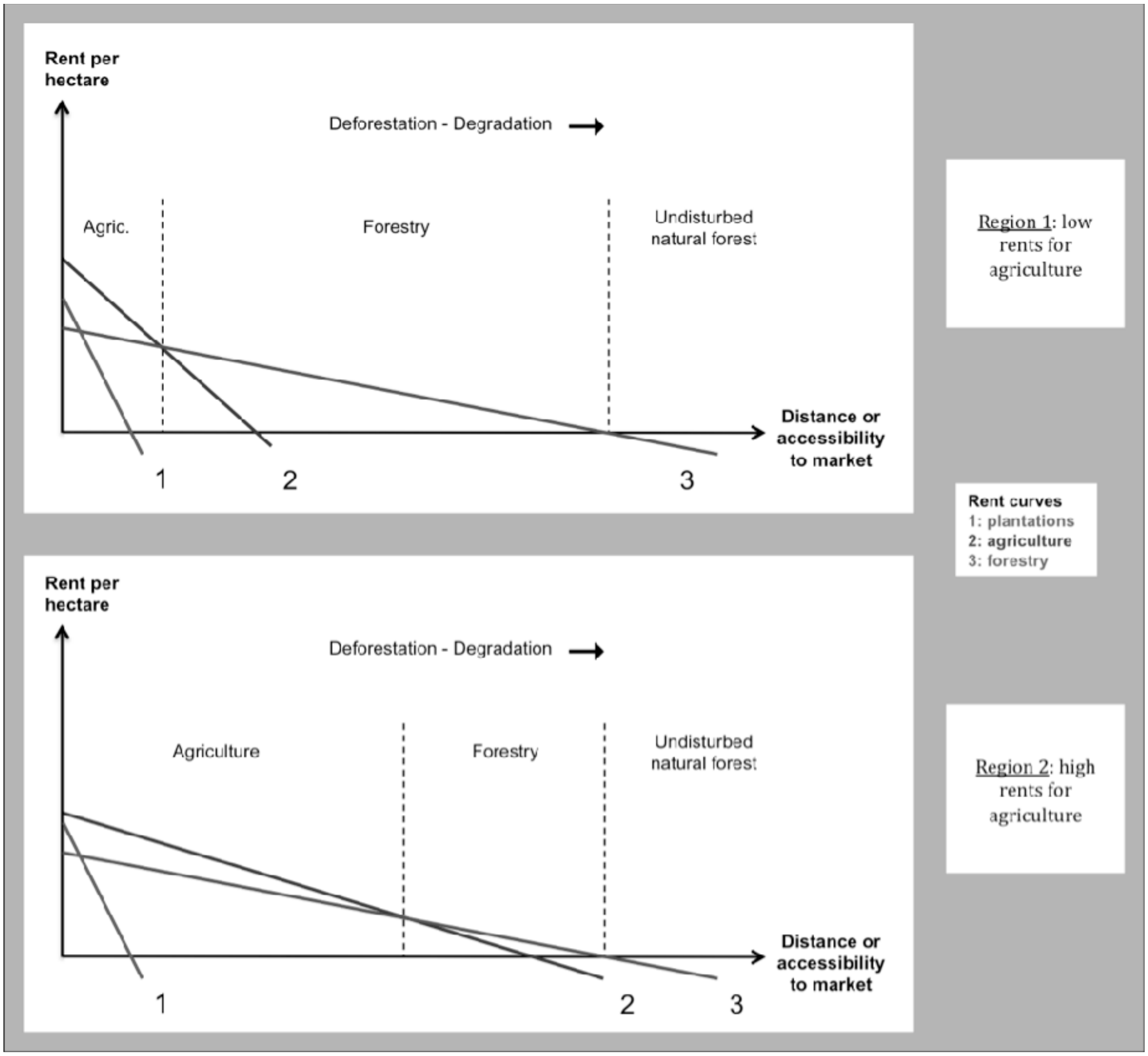

Figure 2: A von Thünen's representation of land uses at $T_{0,}$ (with no timber plantations).

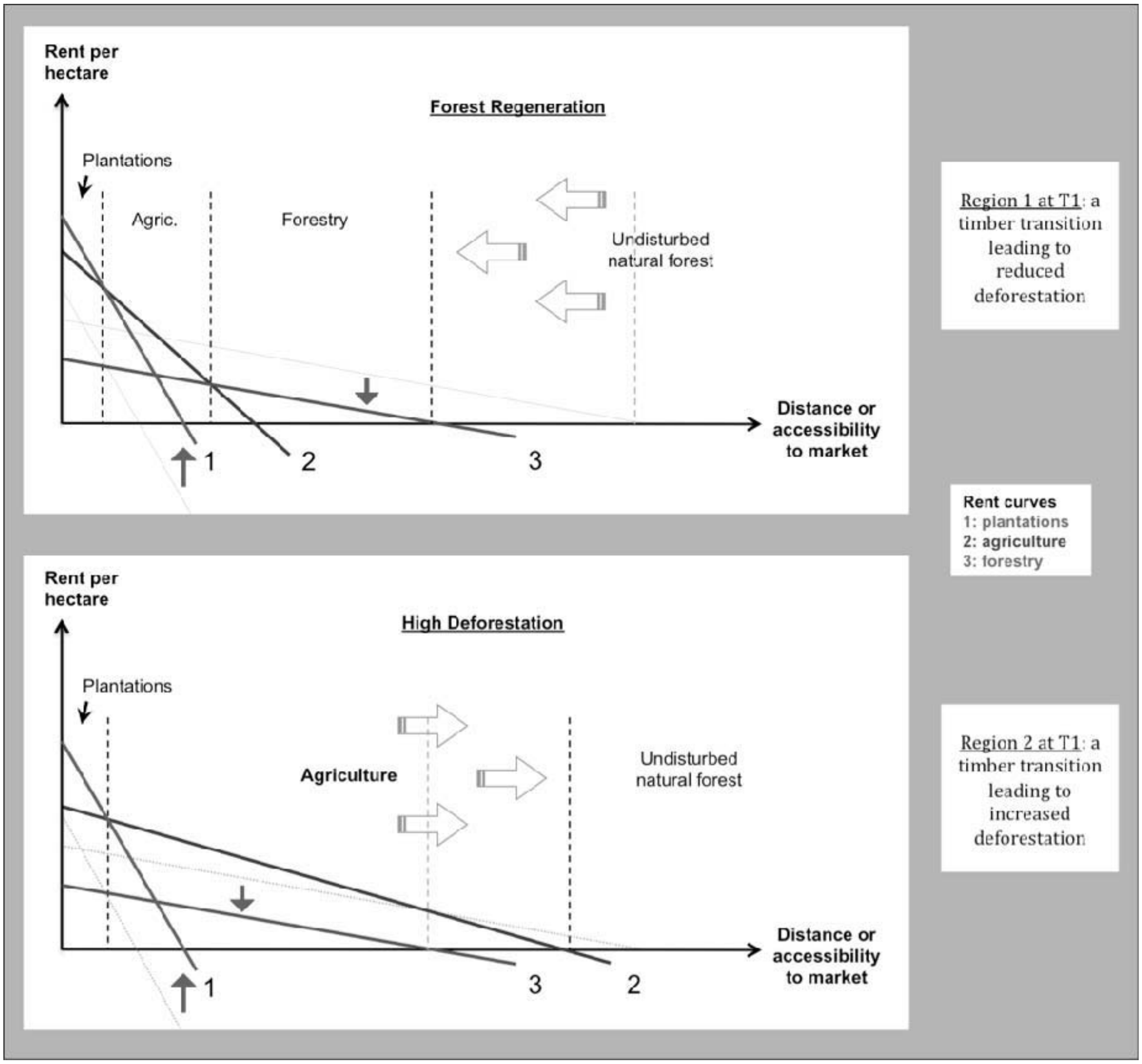

Figure 3: A von Thünen's representation of land use changes at T_1, after a surge of timber plantations.

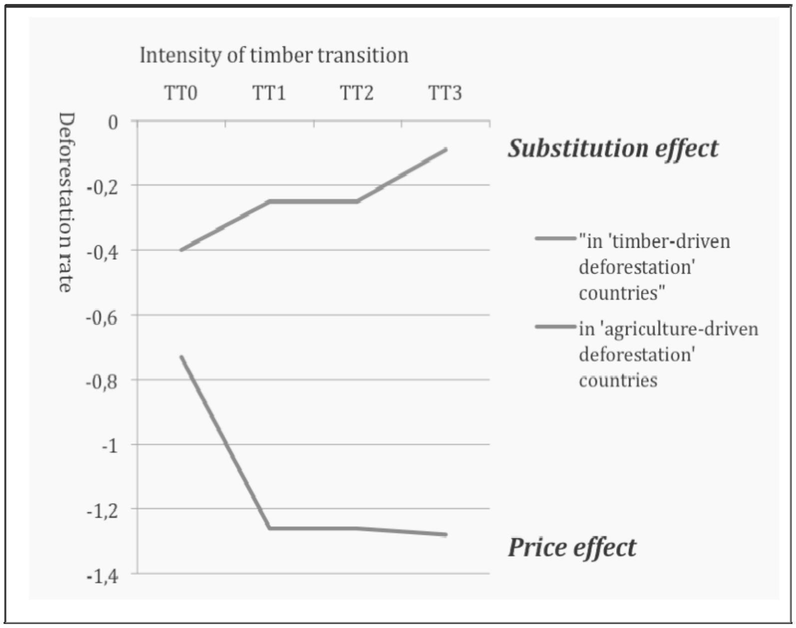

Figure 4: Net impact of timber plantations on deforestation in type 1 and 2 countries

Note: Calculated from Table 3