Remote-sensing evidence about national deforestation rates in developing countries: what can be learned from the last decade

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Abstract

In the present article, I review the literature about the determinants of deforestation (with a focus on developing countries) and shows descriptive statistics of recent deforestation (2000-2012), using newly-released and globally available high resolution remote sensing data on forest loss. I assess recent trends in deforestation to discuss global policy choices and orient international conservation policies.

I also address the requirements for a cost-effective REDD+ policy, compensating trade losses in an open economy exporting agricultural commodities and endowed with tropical forests. Finally, I discuss the challenges of its implementation with a focus on additionality and the effects of international trade and global demand.

Keywords: deforestation; development; international trade, remote-sensing.

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1 Introduction

Deforestation in the tropics remains an important environmental issue in the context of global climate change and biodiversity losses. For example, the International Panel for Climate Change (IPCC, 2014) states that the Agriculture, Forests and Other Land Uses (AFOLU) sector currently represents a quarter of world greenhouse gas emissions.

The purpose of this paper is to provide an update of the determinants of deforestation in tropical countries, and to show its recent trends using a new data-set based on time-series analysis of satellite images, offering a unique level of precision concerning forest losses (Hansen et al., 2013).

These data was mobilised in many recent studies at the sub-national level (Burgess et al., 2012a; Alesina et al., 2014a; Lubowski et al., 2014; Blankespoor et al., 2014; Busch et al., 2015). Indeed, so far, macroeconomic empirical analysis has been based on the widely criticised data provided by the FAO[1], and focused on periods prior to the 2000s. Different data sources may indeed lead to different assessments of global forest resources. According to the last Forest Resource Assessment from FAO (2015), deforestation has been slowing down: from an annual average rate of 0.18% in the early 1900s to 0.08% during the period 2010-2015. This decreasing trend is at odds with another study, Kim et al. (2015), showing that deforestation increased by 62% in the 2000s relatively to the previous decade, using very similar data to

[1] See DeFries et al. (2002); Czaplewski (2003); Grainger (2008); Furukawa et al. (2015) and Kim et al. (2015)

the Hansen et al. (2013) dataset, also uniquely based on land cover imagery processing. Such discrepancy may be due, as explained in Li et al. (2016), to a different canopy fraction adopted in the forest definition in the two methodologies: over 10% in the FAO assessment against a threshold of 25% in Hansen et al. (2013).

The paper is organised as follows. The next section presents the recent trends in forest losses. Section 2 is a literature review of the determinants of deforestation and some simple graphical evidences about potential causes of deforestation in developing countries. Finally section 4 investigates the challenges of REDD+ policies implementation with a focus on addtionality and the effect of trade. Section 5 concludes.

2 Recent trends in deforestation

A recent study estimate the global number of trees at 3 trillion, with about 50% in tropical and subtropical regions (Crowther et al., 2015). This represents half the stock present at the start of human civilization. Recently, the share of this stock that is situated in arid tropics characterised by dryland biomes has been updated and increased of about 10% according to Bastin et al. (2017).

Precise land use estimation has never been easy, it was however improved recently, facilitated by technological improvements such as remote sensing images offered by modern satellites.

In this section, using data at the national level I describe (i) recent global deforestation trends, (ii) the specific trends in a sample of developing countries analysed in Leblois et al. (2017) and (iii) graphical evidence in countries with the largest levels of deforestation.

2.1 World

First, I investigate the global dimension of deforestation from 2000 to 2012, period on which homogeneous deforestation data is available. To assess global trends in different types of forests, I classify them, using the mean latitude, into boreal (43 countries), temperate (40 countries) and tropical forests (85 countries).

The three climate zones are characterised by the same trend of increasing deforestation (see Figure 1), meaning that the objective of stopping deforestation at a global level has not been reached. Moreover, they showed the same pattern until the 2008 financial crisis. After that period, a divergence is observed among the three types of forests[2]. Figure 1 also shows that tropical deforestation represents almost half of overall global forest clearance.

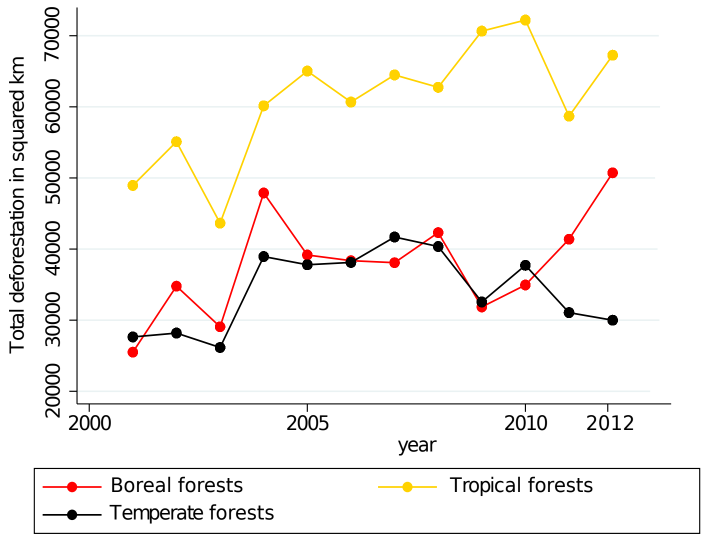

Figure 1: Sum of country-level deforestation (sq. km) under different climates from 2000 to 2012.

2.2 Developing countries

When looking at countries with more than 5% of forest cover in 2000, deforestation rates are characterised by two kinds of trends (Fig 2). Some countries (region names in red) exhibit some positive (afforestation) trends while on the contrary other countries (in green) exhibit volatile but similar deforestation paths. In the latter, changes seem to be subject to more erratic variations, which suggests the presence of common factors such as the impact of world demand and economic cycles driving the deforestation patterns. In both cases, the change in the trend line after the financial crisis is distinguishable, however no strong effect was detected through fixed effects regressions and will thus not form part of the empirical analysis in the following sections.

[2]Note that losses in temperate and boreal forest may be due to sustainable harvesting and deforestation compensated by plantations. Anecdotal observation from Hansen data on-line, shows that the increase in boreal deforestation after 2009 probably corresponds to tar sand exploitation in Canada and increased deforestation in Russia.

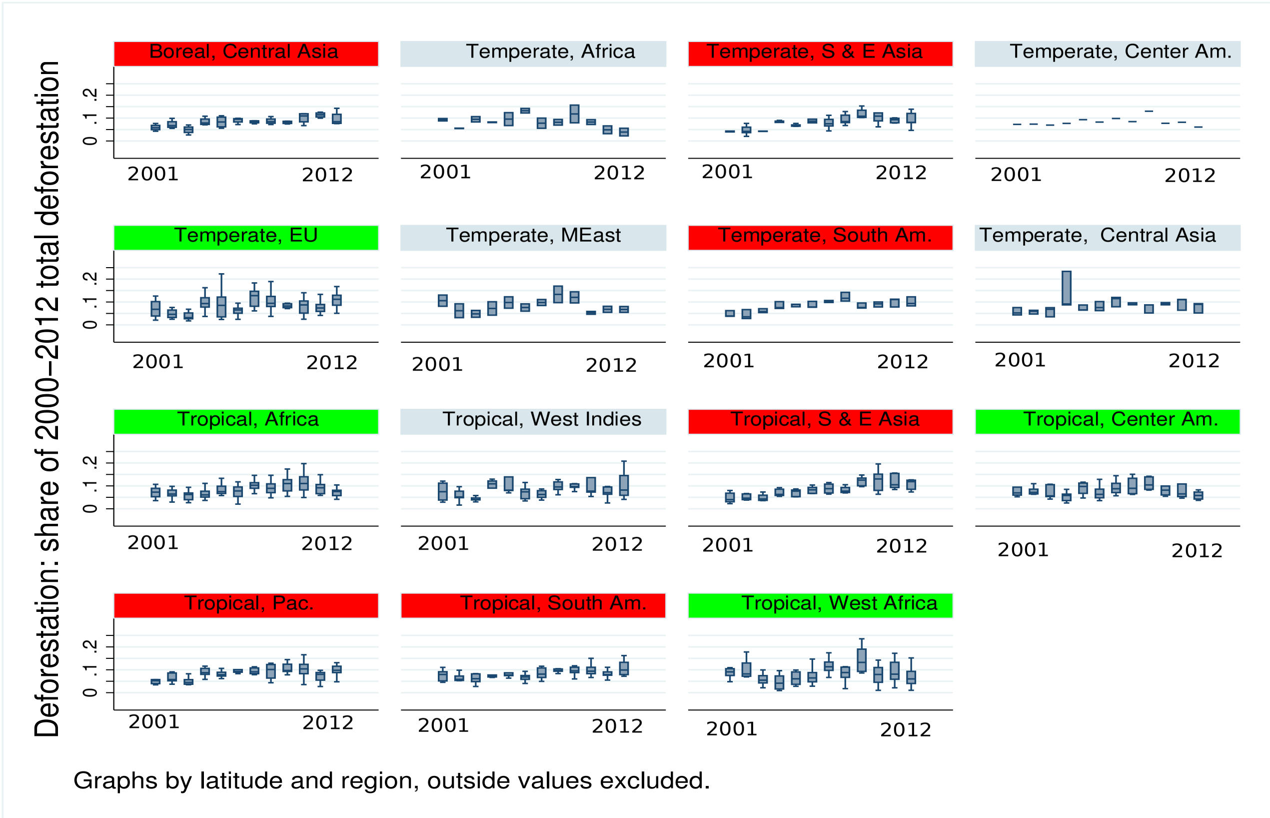

Figure 2: Annual percentage of study period deforestation, by region (restricted to countries with more than 5% of forest in the country area and an average GDP per capita inferior to US$ 10,000) 2001-2012. Lower and upper bound respectively corresponding to the lowest and highest values and box limits to 25 and 75 percentiles, median line corresponding to the median of the distribution.

2.3 Country level deforestation

In this section I consider 30 countries with the largest level of deforestation rates from the sample of Leblois et al. (2017)[3], *i.e.* countries with more than 6,000 km^2 of deforestation over the period 2001-2012, in order to look at national trends.

First, I focus on 6 countries with the highest level of deforestation, above 40,000 km^2 over the period considered. Figure 3 shows the changes in deforestation levels during the period studied for the 6 biggest countries in terms of absolute forest clearance, and Figure 4 shows changes in deforestation in the next 24 countries.

From 2005 onwards, deforestation was reduced in Brazil[4] thanks to stringent national policies, however it may have simply leaked across into neighbouring countries such as Bolivia, Paraguay and Peru. Moreover, considering that global demand may be sustained and geographically widely distributed through international trade, this potential leakage effect could also be tested in other tropical countries.

However, more recent increases in Brazilian deforestation[5] implies that the evolution of deforestation in Amazonia in a near future may cancel out the last decade reductions. This phenomenon, together with the increasing trend of deforestation in Indonesia and pushes for a new framework. The conservation community should maybe consider a new paradigm to design efficient conservation policies globally.

[3] Low and middle income countries, according to the 2015 World Bank definition.

[4] And on a much smaller scale other emerging economies such as China.

[5] Since 2013 and even more since the transition to a new government, (Fearnside, 2016), that abrogated in 2017 the natural reserve status, dating from 1984, of 4 millions of hectares situated in northern Brazil (Para and Amapa states).

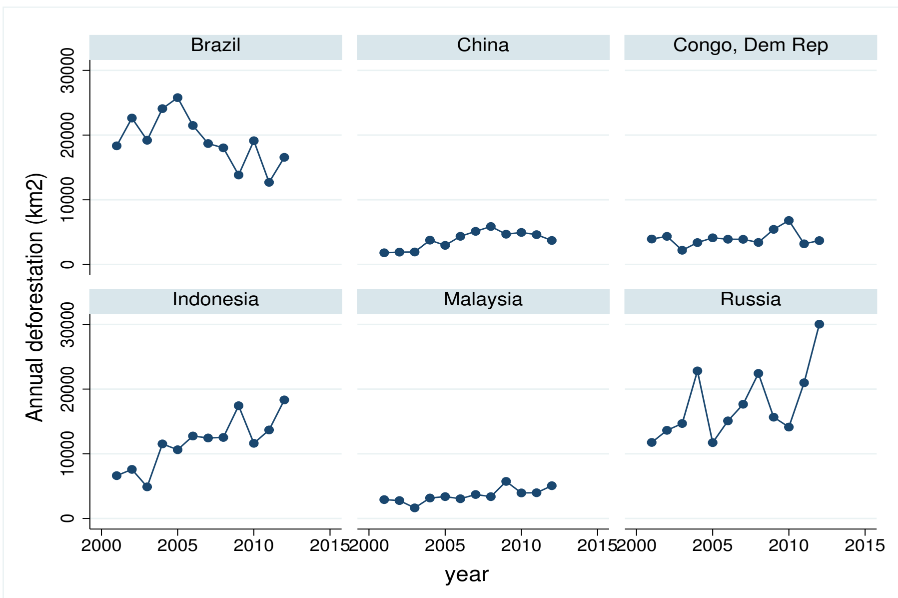

Figure 3: Deforestation in the biggest developing countries, deforestation in 2001-2012 over 40,000 km^2

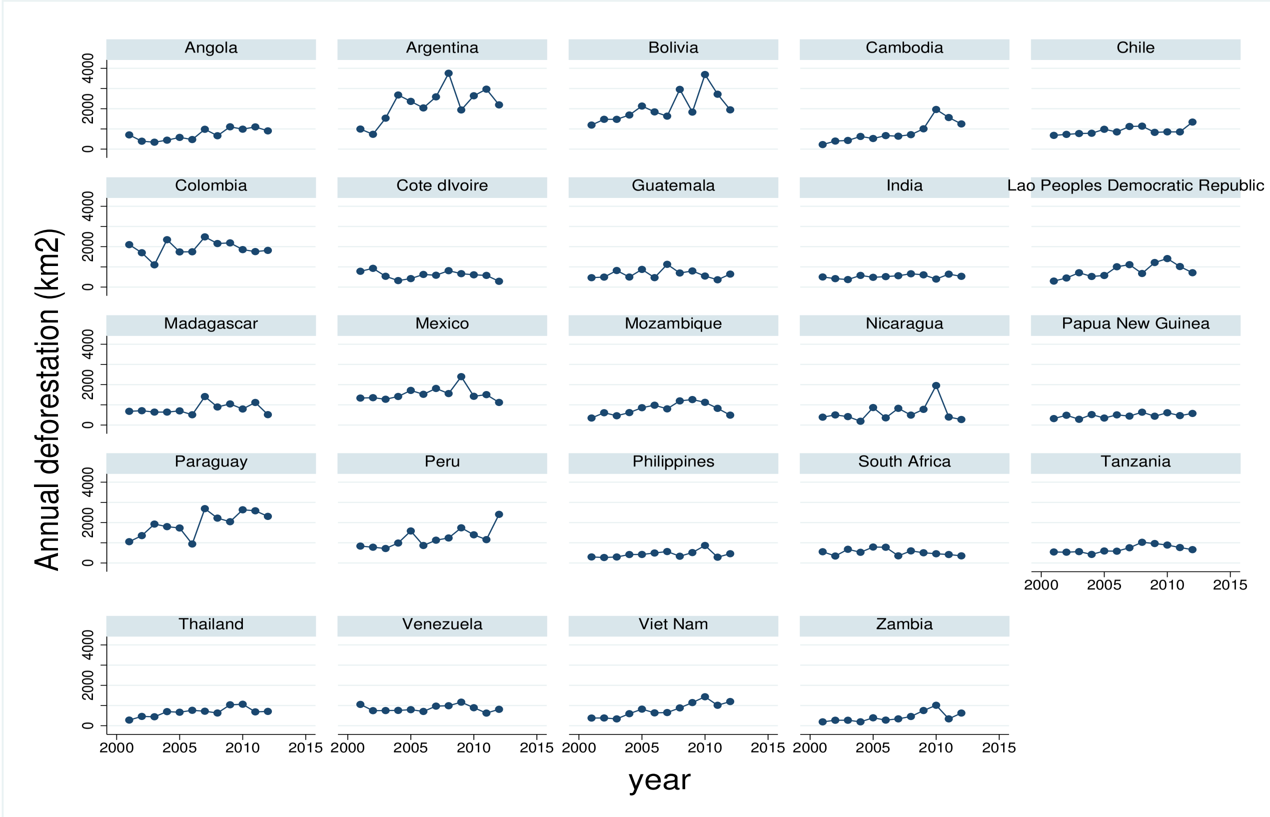

Figure 4: Deforestation in other developing countries, deforestation in 2001-2012 overo 6,000 km^2 (and inferior to 40,000 km^2)

3 Determinants of deforestation: a review

Geist and Lambin (2002) distinguish biophysical, economic or technological, demographic or institutional and cultural factors leading to deforestation. We will focus on economic, demographic and institutional factors.

3.1 Structural determinants

Population density is generally mentioned as a major factor putting pressure on natural resources, including forests. In developing countries endowed with forest resources, rural populations migrate when access to land is improved, and convert forests into croplands, harvest trees for fuelwood, timber and other forest products. Meanwhile, demographic expansion supplies a large number of workers, maintaining the wages of the agricultural sector at a low level (Angelsen and Kaimowitz, 1999). As a result, agricultural rents are high and land conversion proceeds. Since the seminal work of Cropper and Griffiths (1994), several econometric analyses have found evidence that population is positively correlated with deforestation in developing countries.

The so-called Kuznets curve, the inverse U-shaped relationship between income and inequalities, can be extended to the consumption of natural resources and emission of pollutants. It is known as the Environmental Kuznets Curve (EKC). The main insight of such theory is that income and environmental degradation grow together during the first steps of a country's development, and, once a given threshold of income (unique to each country) is reached, environmental degradation starts decreasing while per capita income keeps increasing. It has then been applied specifically to deforestation issues, as described in the geography literature (Rudel et al., 2005) or in environmental economics (Wolfersberger et al., 2015).

First, early development steps are characterised by agricultural expansion and forest clearance. In the short term, an increase in the global income may raise the total demand for agricultural products, leading to agricultural land expansion and in turn promoting deforestation (Angelsen and Kaimowitz, 1999). For instance, over the period 1980-2000, more than 80% of new croplands were created at the expense of previously forested lands (Gibbs et al., 2010).

Then, the industrial sector develops and commands higher rents than agriculture. Some farmers leave their land to move to the cities, where they can take manufacturing jobs with higher wages. Along with this urbanization pattern, agricultural intensification occurs as a result of the increase in physical capital (*e.g.* machines, fertilizers) per worker. In the meantime, the demand pattern changes and the population consumes more non-agricultural based products. The combination of all these macro-trends can lead, in certain cases, to the end of deforestation in a country.

Since the 1990's, many studies have tested the existence of an EKC for deforestation, defined by the underlying forces described above. However, there is no evidence that such a stylised fact is always verified (Choumert et al., 2013). Empirical evidence shows that urbanization can occur without a slowdown in deforestation rates. For example, the urban population (as a percentage of total population) in Indonesia increased from about 30% in 1990 to almost 50% in 2010 (World Bank data). However, over this period, deforestation also increased, notably due to an increase in timber and agricultural exports, as it will be explained in the next sections. This emphasizes the role of trade, leading to a fuzzier relation between population, income and deforestation.

3.2 New insights from a focus on international trade

While about 80% of current global deforestation is supposedly due to agricultural production (FAO, 2015), most of it is traded internationally: few empirical works identified a significant relationship between trade and deforestation at the national level. Among these, Barbier et al. (2005) found that policies improving the terms of trade (i.e. the relative price of exports in terms of imports, corresponding to price competitiveness) in a country with forests increases producers' prices, and thus promotes deforestation. Arcand et al. (2008) have shown that a depreciation of the real exchange rate can increase the exports of commodities in countries from the South, and then increase deforestation.

DeFries et al. (2010) show a positive relationship between openness to trade and deforestation at the national level for the period 2000-2005, arguing that policies should focus on reducing deforestation that is carried out for industrial-scale, export-oriented agricultural production. In the same vein, Hosonuma et al. (2012) shows that commercial agriculture is the first determinant, followed by subsistence agriculture. Finally, Gaveau et al. (2016) examined the effect of industrial plantations in Borneo since the 1970s. These authors find that those plantations has been the main cause of deforestation of old-growth forests in the Malaysian part, and to a lesser extent in the Indonesian part too. However, the limited availability of aggregated data at the national level about the type of agriculture (subsistence vs. commercial) prevents the use of robust quantitative methods.

Leblois et al. (2017) found evidence that trade in agricultural commodities is an important factor in forest clearance and that the impact of trade is predominant in countries still endowed with a large proportion of forest cover.

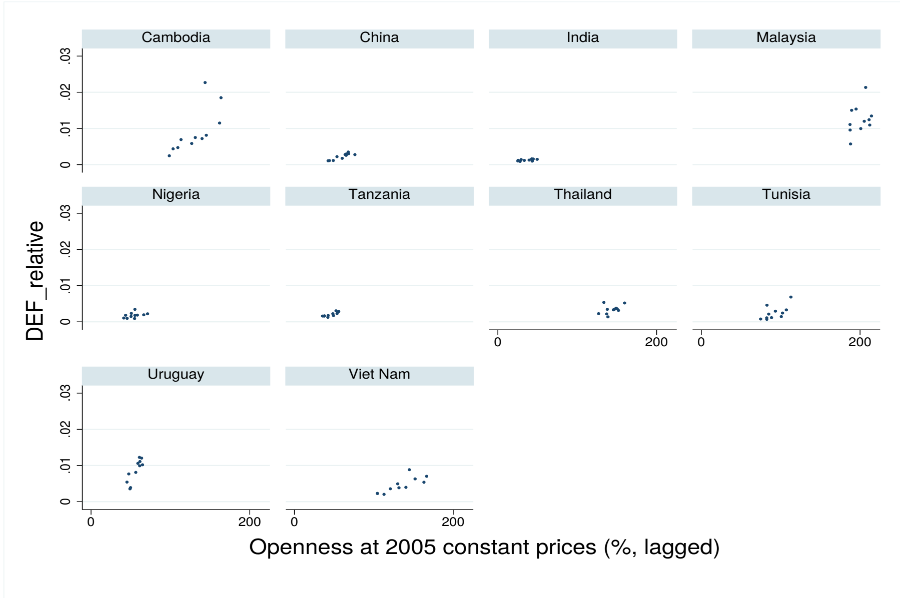

Figure 5: Relative deforestation (deforestation rate of forest cover) in 2001-2012 and openness to trade in selected developing countries.

Recent studies have highlighted trade as a potential driver of sub-national deforestation. Faria and Almeida (2016) show empirical evidence that between 2000 and 2007, when Brazilian municipalities of the *Amazonia* opened to international trade, deforestation increased. This is also the case of studies emphasizing the role of industrial production oriented towards international trade. Schmitz et al. (2015) show that further liberalization would lead to an expansion of deforestation in the Amazon due to the comparative advantages of agriculture in South America. Globally, they estimate, using a spatially explicit economic land-use model coupled to a biophysical vegetation model, that an additional area of between 30 and 60 million ha (5-10%) of tropical rainforests would be cleared, leading to 2040 Gt of additional CO2 emissions by 2050.

Looking at graphical relation between deforestation rates and openness to trade (the sum of exports plus imports, to the country's GDP) in 10 selected countries, a positive relationship arises within (fig. 5) and among (fig. 6) countries.

Main causes of global deforestation are disputed, such lack of consensus among the scientific community leads to the existence of competing eligible ways to design efficient conservation policies. After demographic and economic development, structural transformation has been put forward in the

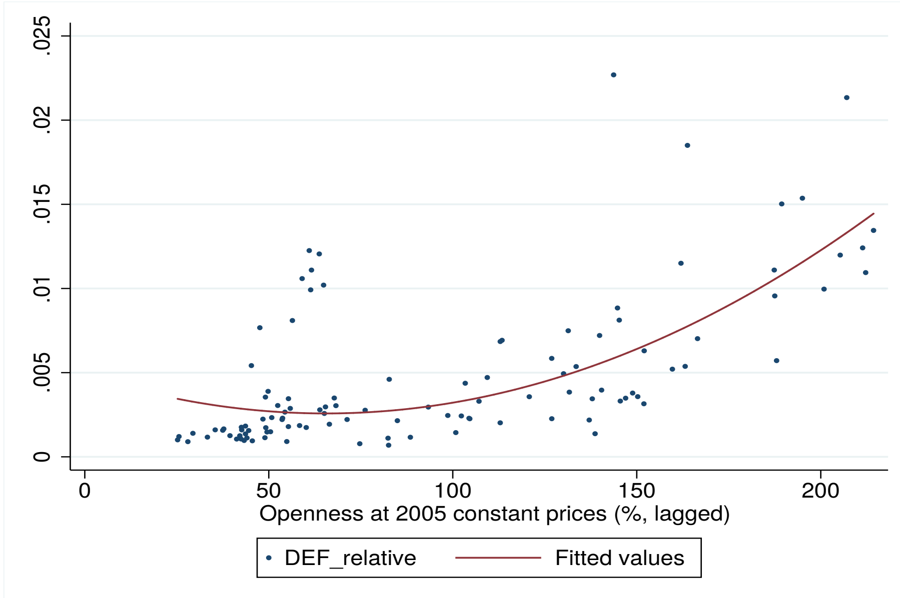

Figure 6: Relative deforestation (deforestation rate of forest cover) in 2001-2012 and openness to trade in selected developing countries: a relationship.

preceding section. However deforestation is still largely driven by agricultural land expansion and openness to trade and this points at the global demand for food products. Such statement leads to consider diets in rich countries as a major factor of change in global land use dynamics. Foley et al. (2011) recommends to play on every channel in order to effectively reduce pressure on global land use.

3.2.1 Trade and forest transition

In this section, we look at the effect of agricultural trade in the light of the forest transition concept (Mather, 1992; Culas, 2012; Wolfersberger et al., 2015) which distinguishes four stages:

- Phase 1: undisturbed forests
- Phase 2: intensive deforestation
- Phase 3: transition is occurring
- Phase 4: net forest cover is increasing

Economic principles from trade theory suggest that a country with a substantial amount of natural resources might develop a system that uses those resources intensively. This is why countries with large areas of forest and arable land export timber and agricultural products. A relation emerging from international commodity markets: the more competitive a country is, the more it may export primary sector commodities, leading to higher pressure on land use.

Recent empirical studies using cross-country panel data focus on the forest transition hypothesis to explain deforestation dynamics (Culas, 2012; Wolfersberger et al., 2015). The forest transition (Mather, 1992) describes changes in the forest stock in a country, in relation to its level of development. It states that forest cover first declines, then stagnates and may finally even experience an increase concomitant with the development of other economic sectors. The latter phase of forest increase may be more or less pronounced, depending on the country. Some developed countries, such as France or the USA, have experienced an increase in forest cover, (Mather, 1992), although limited in space an sometimes highly fragmented. However, if empirical evidence indicates that the same pattern is seen in emerging economies such as India (Foster and Rosenzweig, 2003) or Vietnam (Meyfroidt et al., 2013), it may take a long time or even never be triggered in some other developing countries.

Total accumulated deforestation differs in the Democratic Republic of Congo, where the forest transition has not yet started and land is still largely covered by forests, or in Vietnam, where the large phase of deforestation is over. It is thus reasonable to assume that forest policy and economic incentives related to land use also differ at distinct stages of development. Wolfersberger et al. (2015) found that determinants of land-use changes differ depending on whether a country is before the turning point or has already reached it.

In presence of international trade, forest transition may be linked to deforestation rates. This can be explained in terms of the opportunity cost of using an additional unit of the resource, or to put it differently, in terms of comparative advantage in land use. In countries with large forest stocks, there is a strong incentive to specialize in deforestation and agricultural activities in order to develop, since the resource is abundant (and thus cheap to extract). In countries with a low stock of forest remaining, the opportunity cost of specializing in the production of goods that are intensive in this type of activity is much higher. Cutting down an additional unit of forest is expensive and the few remaining forests may provide important environmental services and meet local wood supply needs. The same reasoning can be applied to the study by Robalino and Herrera (2010) which finds that opening up to trade may not always imply deforestation in a developing economy. Countries with low remaining forest stocks will prefer to import goods that are intensive in land use, while countries with large forest stocks will prefer to export goods that are intensive in land use.

Leblois et al. (2017) shows that the effect of trade on deforestation depends on the stage where the country stand in the forest transition process.

Since the natural resource is abundant and the cost of extraction is low in countries in phases 1 and 2, the value of internationally traded agricultural commodities provides a source of income and opportunities for development. This may explain why deforestation is boosted by agricultural exports value in phase 1 and (to an even greater degree) phase 2.

In countries in phase 3, the opposite relationship is found: trade in the agricultural sector lowers deforestation. In these countries in the late transition phase, cutting down an additional hectare of forest is costly, with regard to the low remaining stock of the resource (high opportunity cost). This effect may also be interpreted spatially at an infra-national scale: the remaining forests are far from the market, (and thus have a higher extraction cost). They also have a high environmental value, for instance as an important reservoir of terrestrial biodiversity and ecosystem services - water, carbon, pollination etc.

These results show the usefulness of considering a country's forest transition phase in REDD+ policies, especially for those countries in the earlier phases, cf. section 4.

3.2.2 Land deals and biofuels

The impact of biofuels on deforestation has already been documented in Brazil (De Sa et al., 2013). This may have a strong impact on deforestation trends, since energy one of the main scarce (and expensive) resource needed for development and growth. This, in spite of its relative efficience in reducing emissions: biofuels release about 17 to 420 time more CO2 equivalent that the reductions it provides but replacing fossil fuels (Fargione et al., 2008)

A rush on arable land has recently been observed, pushed by markets anticipation increasing price of agricultural commodities and globablization of land markets, also authorised by poor land tenure in developing countries. Although some studies focused on the determinants of land deals (Arezki et al., 2013), to our knowledge none looked at its actual impact on deforestation.

The available LandMatrix database (ILC) et al. (2015) make the inventory of large land deals globally since 2000. Some countries show a relatively important relationship between recent deforestation and large land deals, this is the case of Indonesia (cf. Fig. 7), Laos (Fig. 8) and in a lesser extent in African countries (Fig. 9). However, in most developing countries, such

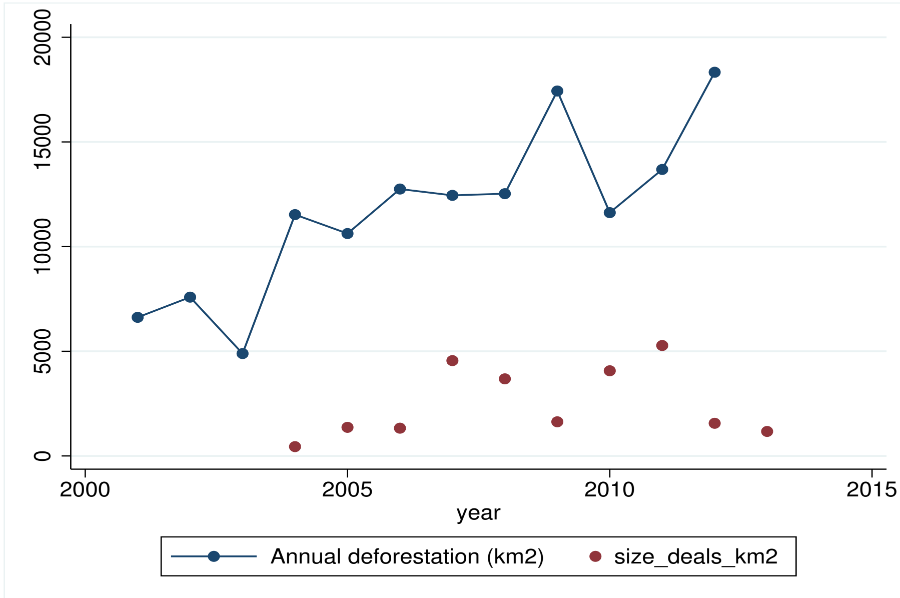

Figure 7: Deforestation in 2001-2012 and land deals in Indonesia.

relation can not be enlighten graphically (Fig. 10). This is probably because those deals are still recent, and many of them were not converted into investments. They thus did not lead to land use changes or even simply because the deals only had a speculative objective for the investor.

3.3 Other determinants

3.3.1 Conservation

The effectiveness of protected areas in preventing deforestation in the tropics has already been thoroughly examined. For instance, Haruna et al. (2014) discuss the importance of forward-looking plans when implementing those protected areas in Panama from 1992 to 2008; Robalino et al. (2015) study the optimal spatial distribution of these policies in Costa Rica. Finally, this subject has been looked at by two other research teams (Blankespoor et al., 2014; Maher et al., 2013) working with high resolution data and showing that different levels of protection may have very different impact on conservation.

However, Pfaff et al. (2015) find that protected areas tend to be located on land facing less pressure that would reduce the efficiency of such policies. This is consistent with Ferretti-Gallon and Busch (2014) and Heino et al. (2015) results showing limited impact of protected areas on deforestation at the national level and high heterogeneity across countries.

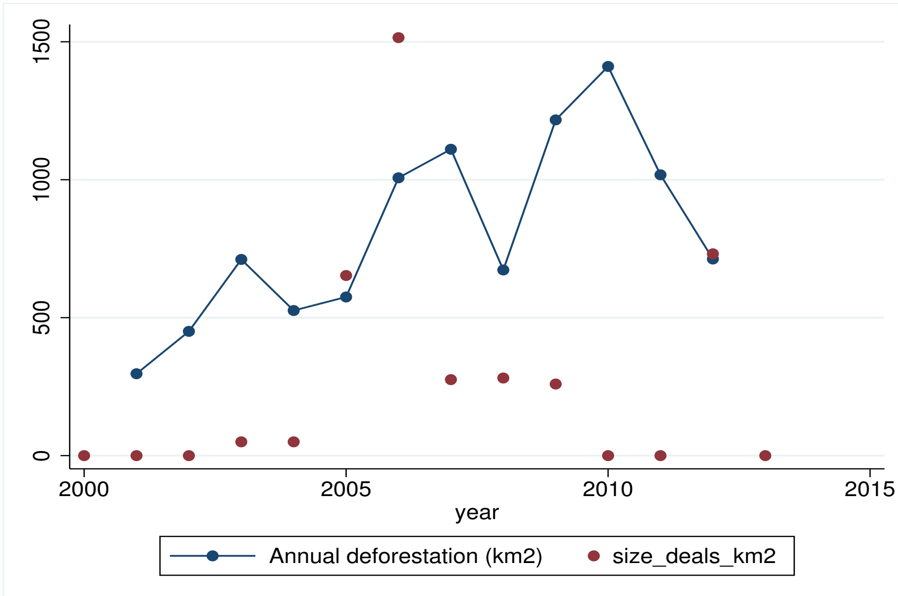

Figure 8: Deforestation in 2001-2012 and land deals in Laos.

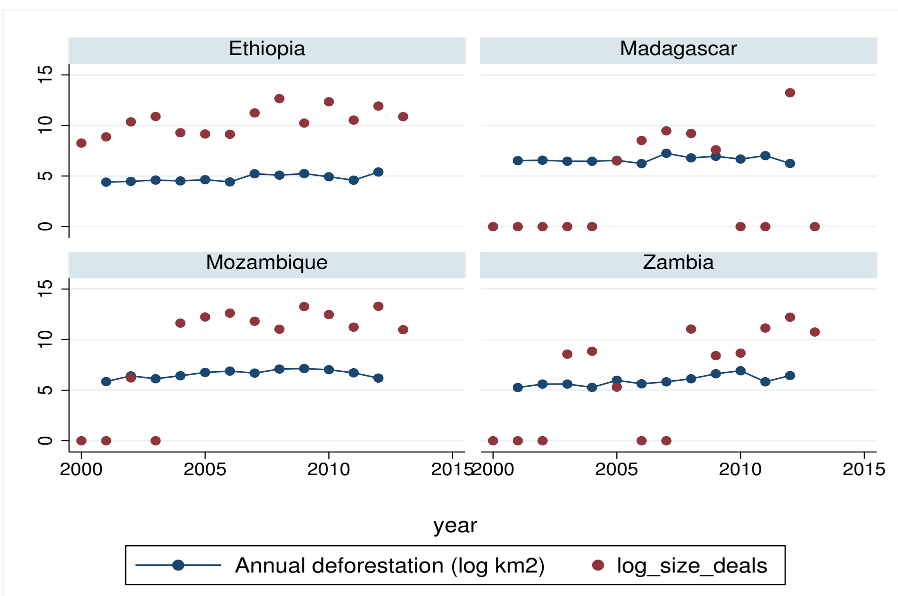

Figure 9: Deforestation in 2001-2012 and land deals in Africa.

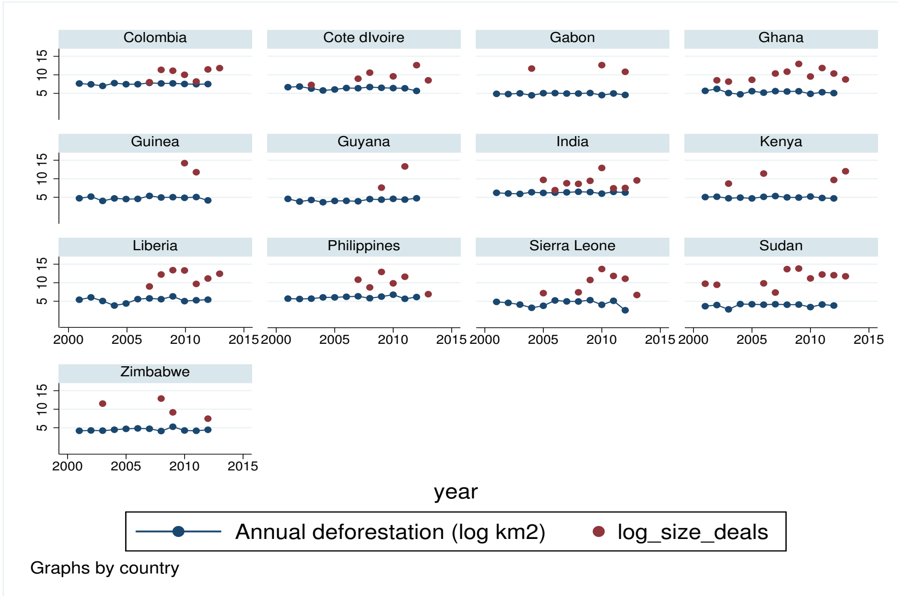

Figure 10: Deforestation in 2001-2012 and land deals, in countries with significant land deals but where there is no *a priori* relationship.

Amin et al. (2015) nevertheless found that, if leakage reduces the amplitudes of reduction in deforestation, it does not annihilate it. Moreover Nolte et al. (2013) has found that lands under sustainable use, strict protection as well as indigenous land, efficiently reduced deforestation in the 2000's, in an empirical estimation on 264 Amazonian municipalities. Barber et al. (2014) found it is true even when properly controlling for access to transportation (different types of roads and navigable rivers).

This result validates Nelson and Chomitz (2009, 2011) who showed that strict protected areas were more efficient in reducing deforestation than multi-use protected areas, although endogeneity may exist in the localisation of multi-use areas (multi-use area could have been localized in certain types of landscape or specific for other reasons, limiting the consistency of the comparison accross areas), generally located in zone of higher deforestation pressure. However spatial leakage is not controlled in those analyses. The robustness of such a result is limited: other studies (Nelson and Chomitz, 2011; Ferraro et al., 2013) show a very high heterogeneity in the positive relation between strictness of protection and performance in terms of deforestation reduction within and across countries and continents. Pfaff et al. (2014) also investigated the efficiency of governance in managing protected areas (PAs) in one specific state of the Brazilian Amazon. They found that the beneficial effect of PAs was actually driven by location: PAs with a strict-blocking governance were assigned to areas with low pressure (weak development and poor population density), i.e. in areas where deforestation was less likely to take place even in absence of public policies. For this reason, they claim that sustainable use areas helped to significantly reduce deforestation rates. The authors used spatial data only available at the state-scale. Moreover, Rasolofoson et al. (2015) has showed that community forests are not always reducing deforestation, they are efficient only if they do not allow commercial use of the forest. As well, Bottazzi and Dao (2013) studied the impact of political processes on forest harvesting in the Bolivian Amazon. They took into account some spatial impacts only visible at the state level and found that collective property rights were attributed to remote areas with little or no pressure on forests. This explained the fact that this regime of land rights exhibited less deforestation.

Sustainable forest management (SFM): a debated role

Brandt et al. (2016) present a methodological approach for assessing SFM policy in tropical forest ecosystems and apply it on a case study on Republic of Congo, which implemented a SFM-based forestry law since 2000. Using incomplete compliance with the forestry lax and quasi-experimental matching they found that SFM may induce even more deforestation because forests are then associated with more timber production, foreign capital and international demand.

Recently, a large debate opposed them to other authors (Karsenty et al., 2017), about the relative efficiency of SFM's in conservation objectives in the Congo basin. SFM's were especially compared to forests managed by indigeneous populations that has been shown be efficient in South America Nepstad et al. (2006).

Zimmerman and Kormos (2012) argues that, although some sustainable management of tropical forests are successfull in reducing deforestation at local-community scale, it is likely to lead to the degradation and devaluation of primary tropical forests as surely as widespread conventional unmanaged logging does today. This argument beg for a reevaluation of the UNFCC proposals to apply a REDD+ subsidy for the implementation of SFM logging.

3.3.2 Political factors

Institutional quality has been found to be critical in the deforestation processes in many statistical cross-country studies, i.e. at the national level (Bohn and Deacon, 2000; Barbier and Burgess, 2001; Bhattarai and Hammig, 2001; Culas, 2007; Nguyen-Van and Azomahou, 2007). Because of corruption and high tenure costs, landowners are encouraged to turn their land over to agriculture, in order to define property rights[6]. More broadly, weak governance in developing countries with forests often leads to higher rates of deforestation (Barbier et al., 2005).

Burgess et al. (2012b) shows how subdividing administrative jurisdictions in Indonesia has led to an increase in deforestation, through a decrease of prices in the local wood market. Their study provides new evidence on how potentially corrupt bureaucrats and politicians respond to incentives, by increasing the rate of extraction and thus maximizing their rents when their official market power diminishes.

Alesina et al. (2014b) shows that the level of deforestation in Indonesia is positively related to ethnic fractionalisation at the district level. The authors exploit exegenous (allowing proper statistical estimation of causal relation) timing of variations in the level of ethnic heterogeneity due to the creation of new jurisdiction and provide evidence of a lower control of politicians, through electoral punishment, in more ethnically fragmented districts. This would imply according to the authors that under ethnical fractionalisation, decentralization may reduce deforestation.

3.3.3 Conflicts

Butsic et al. (2015) show, using Democratic Republic of Congo data, that conflict and mining genrally induce more forest loss. However, they also proved that in areas with high level of mining, conflict can alternatively lessen deforestation. The negative impact of protected areas on deforestation remain even during conflicts. In Rwanda, Ordway (2015) has found that 96% of forest loss during conflict across the landscape occurred in protected areas.

Many of the aforementioned determinants were confounded in a meta-analysis of micro and macro econometric estimations of determinants of deforestation globally (Busch and Ferretti-Gallon (2014)), including additional local variables such as road network density, commodity prices, protected areas and payment for ecosystem services among others.

3.4 Patterns of spatial effects and leakage

Following a seminal paper of Chomitz and Gray (1996), recent work focussed on the very local determinants and spatial diffusion of deforestation. They for instance show that deforestation is largely due to opening roads or other routes facilitating transports such as navigable rivers (Mertens et al., 2002; Pfaff et al., 2007; Robalino and Pfaff, 2012). Opening a road for economic

[6] On the productive use of land, see for example Araujo et al. (2009) for a study from Brazil.

developement or for deforestation may indeed open the access to many new intact forest plots, potentially leading to hysteresis phenomenon (which consequences reinforce its causes) in the diffusion of deforestation which may cause vicious cycles. Such spatial effects has been mainly studied within the Amazonia Legal (Aguiar et al., 2007; Alves, 2002).

Amin et al. (2015) analysed the interactions between conservation and deforestation decisions to test the former efficiency. The authors model deforestation decisions as non-cooperative game between municipalities, in which forest is a public good and deforestation allows production of private goods. Deforestation decisions are empirically found to be strategic complements (from one municipality to another) and only *integral protected areas* and *indigenous lands* are found to efficiently reduce deforestation, while *sustainable use* would increase it.

Kleinschroth et al. (2017) show that logging (even certified by *FSC*) lead to marked loss of roadless space in intact forest landscape (IFL) of the Congo Basin, with a rapid road network expansion between 1999 and 2007.

The existence of such spatial effects also emphasize the limits of international public policies trying to bound deforestation by favorising legal deforestation on the expense of illegal activities. Once the roads are openned by legal deforestation the cost of deforesting plots that are nearby is reduced and incentives to deforestation thus increase.

Moreover, the literature (Alix-Garcia et al., 2012) has shined light on some spatial leakage effects: when reducing deforestation in a country or a region it may lead to an increase of deforestation in neighbouring regions. It is the major limit to compensation policies for reducing deforestation since it may simply deplace the problems to another place. This is why additionality (actual reduction compared to a control scenario) of compensation policies has been the main issue discussed in recent global conservation policies.

3.5 Border effects for robust statistical identification

Cuaresma et al. (2017) uses satellite data on forest cover along national borders worldwide. Controlling for trans-border geo-climatic differences, they find that income per capita is the most robust determinant of differences in cross-border forest cover (and even higher at earlier stages of economic development) emphasizing the existence of an environmental Kuznet curve for deforestation, sometimes called forest transition when highlighting the role of sectoral reallocation within national economies.

Burgess et al. (2017) reveals a sharp discontinuity at the border – in 2000, Amazon on the Brazilian side of the border is more likely to have been deforested – and between 2001 and 2005 annual forest loss in Brazil was around four times the rate on the other side of the border[7]. However, in 2006, just after the Brazilian government introduced a raft of policies to curtail illegal logging, these differences disappear and Brazilian rates of forest loss fall to those observed across the border. These results demonstrate the power of the state to affect whether or not natural resources are conserved or exploited even in the furthest reaches of the Amazonian jungle. When looking at the robustness of such results in other tropical forests (RDC and Indonesia), the authors find that the forest cover losses do not seem to be due to a deterioration of national deforestation policies in the latter countries. However, the absence of strong national environmental policies likely disabled these countries to counteract the increasing local and market pressure that led to increasing forest losses in the period.

4 Remedies: REDD+ policies to compensate for trade effects?

REDD (Reducing Emissions from Deforestation and forest Degradation) was officially created during the Bali (2007) and Copenhagen (2009) Conferences Of Parties (COP), with the objective of protecting the world's remaining primary forests. In 2008, at the Poznan meeting, REDD became REDD+, as it was decided to broaden the mechanism and integrate activities enhancing carbon stocks and promoting sustainable forest management.

Essentally, REDD+ is based on three phases. During the first phase, countries have to define a national strategy. Most countries are currently in this phase. During the second phase, participants will have to implement their REDD+ strategies, and to develop policies and measurement tools. Finally, countries will then receive payments based on their performance for deforestation avoided and low-carbon development efforts during the last phase.

Initial enthusiasm of developing countries for REDD+ projects seem to have halted, and the use of such mechanisms has thus been reduced over recent years (Simonet et al., 2014). The main factors causing such a reduction are probably the low current price of carbon on international markets and the lower capacity of new countries entering the mechanism to deal with its complexity and the red tape it generates. However, it may also be explained by the objectives of REDD+: environmental protection and rural development, which can be perceived as being negative at the local level (Pokorny et al., 2013). Delacote et al. (2017) show that REDD+ project location is strongly

[7] Allowing to run a regression discontinuity design (RDD) and thus get reliable statistical estimates.

influenced by project manager objectives (environment, development or external funding) and that additionality of the considered REDD+ projects is influenced by this objective.

The big question is thus the estimation of additionality, corresponding to the actual reduction of land use changes that a country has undertaken, compared to the 'business as usual' scenario. This counterfactual, *i.e.* the path the country would have followed without any incentive from the REDD+ program, is the keystone of the additionality estimation. It however largely depends on hypothesis on public policies and the development and growth path.

One may now wonder what should be the appropriate REDD+ response to such economic mechanisms. How can a country with forests be compensated, financially, for loss of international exports? Trade is, above all, a source of income that can be reinvested in the economy, increasing local demand and so on. In addition, although less quantifiable, participation in the global market allows links to be created with other countries. If REDD+ funding does not take these aspects into account, then developing countries will receive suboptimal compensation, thus undermining their economic development path. Moreover, lowering the pressure on forest resources by increasing the intensification of agricultural production also has a cost that will have to be included in international agricultural prices in the long-run. The trade-off between clearance of forest land cover and either reducing agricultural exports or intensifying agriculture will only be modified by REDD+ programs through an increased opportunity cost of forest clearance.

This reasoning can also be applied at the national level. Under current development paths, agricultural development generally means more land cultivated and thus more deforestation. Although it could be based on rational and efficient land intensification and sustainable land-use, Phelps et al. (2013) emphasize the possibility for intensified agriculture to actually increase future deforestation. Indeed, a more productive agriculture might lead to increases in rents and thus favour the expansion of croplands, at the expense of forests. The authors underline the importance of this possible outcome as agricultural intensification has become a centrepiece of public policies to reduce deforestation.

In conclusion, REDD+ mechanisms need to be cost-effective and give the right incentive, *i.e.* efficiently compensating for opportunity costs of hindered agricultural development. The issue of additionality is even exacerbated by the the trade effect, that makes the relation between deforestation and income even more complex and difficult to apprehend and lead to significant differences in the estimation of opportunity costs of reducing deforestation.

5 Conclusion

As a conclusion I would like to underline the existence of some determinants of deforestation that have not beeen discussed and that may be interesting to look at in further research.

First, it is necessary to consider different types of forest cover depending on:

- Latitude (or rainwater availability: arid vs humid climate of forests). The above-mentionned meta-analysis (Ferretti-Gallon and Busch, 2014) indeed put forward the importance of wetness in deforestation. It emphasize the fact that deforestation processes may differ in distinct ecosystems and regions, where deforestation is not motivated by the same goal (smallholder vs. pastures, fuelwood vs. roundwood, staple-crops vs. biofuels).

- Geography (deforestation for coffee production in Ethiopia or the Andes ni Latin America) as well as ruggedness or elevation.

- Quality of forest cover (primary vs. secondary forests). Further research could look at the degradation of intact forest landscapes that is probably very specific.

Second, land use change dynamics should be taken into account. For instance considering the remoteness (presence of roads and other routes such as rivers) and spatial contagion of deforestation and conservation may improve the predictive capacity of models regarding the spatial spread of deforestation. The accuracy of such projections may also be improved by considering the suitability of land for different crop growing, allowing to control for variations of prices of agricultural commodities that could change opportunities for deforestation in different region of the world.

Finally, the REDD+ framework definitely needs an integrated analysis of the carbon storage (including soils and allowing sound trade-offs among land uses in forests), in order to orient local conservation policies and make them coherent globally to reduce greenhouse gas emissions.

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