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DR n°2011-01

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Synergy effects of international policy instruments to reduce deforestation: a cross-country panel data analysis

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ABSTRACT

Safeguarding tropical rainforests is one of the most important challenges for the future, particularly to mitigate climate change. The international community has actively sought international policy solutions to curb deforestation in tropical countries. Debt-for-nature swaps and certification of sustainable forest management have been implemented by NGOs. Some states are currently negotiating the implementation of the REDD (*Reduced Emissions from Deforestation and Degradation)* mechanism, a North-South financial transfer to compensate countries for avoided deforestation. However, little is known about the efficiency of these instruments. We argue that they may have a double effect: an expected direct impact on deforestation linked to the conditionalities of instruments, and an indirect impact due to their feedback effects on macroeconomic variables, affecting in turn the drivers of deforestation. The second effect is often overlooked by policy makers. The objective of the paper is to disentangle the two effects for different categories of forest countries. We conducted a panel data analysis for the period 1990-2005 and show that cluster analysis of tropical forest countries would be more relevant if it were based on relative forest endowment. On the basis of econometric results, we can recommend differentiating policy instruments according to the relative forest abundance of each country. Debt reduction programs contribute to the reduction of deforestation in all countries. Countries with abundant forests are locked in a development pathway based on overexploitation of their forests making them less responsive to incentive measures. In countries with average forest endowment, we recommend output-based REDD, whereas in countries with low forest cover, either input-based or output-based REDD mechanisms should be efficient.

1. Introduction

Tropical deforestation is not a recent phenomenon but has become a growing concern in recent years because of its global environmental impacts. Between 1990 and 2005, l forest area decreased by an average of 13 million hectares per year (excluding reforested area)

(FAO, 2005), with major consequences for climate and biodiversity. Deforestation is now the second leading cause of greenhouse gas emissions, just behind industrial emissions. Moreover, since 50 to 90% of the world's species are sheltered in tropical forests (WCED, 1987), deforestation also contributes to the acceleration of biodiversity losses.

Although tropical forests are mostly located in low income countries, developed countries are aware that deforestation is a global problem and that a "laissez-faire" policy will jeopardize the future of the planet and their own development paths. The international community is thus actively looking for global solutions and is trying to identify policy instruments that could persuade tropical countries to curb their deforestation. Deforestation is mainly due to the expansion of arable land, the need of local populations for fuelwood (Chomitz, 2007), and the country's dependence on foreign exchange earnings: trade in tropical timber and export crops, at the expense of forest conservation, is often the easiest and most accessible way to respond to these economic pressures. Developing countries are consequently not prepared to reduce their deforestation activities without compensation. They argue that a global solution to the deforestation issue must include a North-South transfer scheme to compensate for the revenue foregone, as well as for their costly efforts towards monitoring and controlling the exploitation of their forests – often in a context of illegal logging by local and foreign corporations, and corruption.

Various international mechanisms have been tested in the past and new proposals such as the REDD[1] scheme are currently on the negotiation table. These may be trade measures for tropical timber or North-South payments, either to finance the costs of forest conservation policies in deforesting countries; or to remunerate avoided deforestation. These compensations can be monetary transfers, debt relief, or the award of tradable emission rights reflecting the CO_2 emissions saved through avoided deforestation.

These policy instruments are likely to have a double impact on deforestation: a direct impact linked to the conditionality of transfers and the direct consequences of trade interventions on the price of timber, and an indirect impact due to their potential feedback effects on economic variables which are themselves drivers of deforestation, such as urban and rural income, poverty rates, agricultural productivity, and foreign exchange earnings. These effects -which are often overlooked in policy-making discussions- can either reinforce the direct impact, or

[1] Reduced Emissions from Deforestation and Degradation

attenuate it, therefore reducing the longer term efficiency of international instruments to limit deforestation.

The objective of this paper is to explore the relative capacity of international policy instruments to curb the global rate of deforestation: we conducted a country-level panel data analysis of the main drivers of deforestation, which in turn, helps forecast the direct and indirect impacts of policy instruments proposed by the international community. For econometric estimations we used a data base that covers the period 1990-2005, allowing us to capture the most recent deforestation dynamics. In contrast with other available studies that often provide estimations per continent, we reveal that cluster analysis would be more relevant if it were based on the relative forest endowment of countries. We demonstrate that policy instruments such as expansion of protected areas and agricultural modernization will affect countries differently, depending on their relative forest cover. We also show that North-South compensation transfers can have perverse effects by indirectly creating new incentives to deforest. Debt relief appears to be the only policy that is efficient for all types of countries.

The paper is organized as follows. In section 2 we provide a historical review and a description of international policy instruments to limit deforestation. In section 3 we present the data and model specifications. In section 4 we analyze our results and make recommendations concerning the adequacy of international policy instruments with respect to the characteristics of the countries concerned.

2. International policy instruments to reduce deforestation

2.1. Historical review

Although genuine multilateral negotiation only started at the 11th Conference of Parties (Cop) of the UN Framework Convention on Climate Change (UNFCCC) in Montreal in 2005 with a proposal for a new North-South transfer mechanism to reduce emissions due to degradation and deforestation (REDD), the international community has been aware of the deforestation issue since the late 1970s and several policies have already been tested with mixed success.

As early as the 1970s, developed countries pressed the South to implement sustainable forest management. However, developing countries, grouped in G77, demanded that a global forest fund be created to finance "opportunity costs foregone", arguing that developed countries shared responsibility in tropical deforestation through their unsustainable consumption of tropical forest products (Humphreys, 2008). But developed countries rejected this proposal and despite renewed efforts, all *"international forest negotiations (...) failed to resolve the* *issues of finance and technology to the satisfaction of developing countries*" (Humphreys 2008). The 1992 Rio Summit successfully launched the Framework Conventions on climate change and on biological diversity, but negotiations on forest management again failed to reach a consensus. Five years later, the Kyoto protocol only succeeded in including afforestation and reforestation in the Clean Development Mechanisms (CDM), as projects for the reduction of emissions in developing countries. But it left aside the crucial issue of deforestation.

In the face of blocked multilateral negotiations, self-supporting initiatives emerged: the most well-known are the debt-for-nature swaps initiated by the World Wildlife Fund (WWF) in 1984, to enable developing countries to reduce their debt while increasing their budget for conservation activities. NGOs negotiated the reduction of the debt of developing countries with international banks outside international official agreements, and in return developing countries committed themselves to an environmental conservation agreement. Another initiative by NGOs is the Forest Stewardship Council (FFC), which promotes timber product certifications to stop illegal trade which "*dwarfs legal production in some countries*" (FAO and ITTO, 2005) and to promote sustainable forest management. Some countries have also invested in bilateral agreements: for instance in 1998, the United States enacted the "Tropical Forest Conservation Act" (TFCA) to "*offer eligible developing countries options to relieve certain official debt owed the U.S. while at the same time generating funds to support local tropical forest conservation activities*" (US Department of State website)[2]. Moreover, outside actual international negotiations or current bilateral agreements, developing countries have proposed "groundbreaking deals" to some developed countries to protect rainforest. For example in 2007, the government of Ecuador declared it was ready to renounce exploiting the oil resources located under Yasuni National Park if the international community compensated the loss of revenues[3], while the same year, Guyana offered Britain the management of one million acres of rainforest in exchange for financial transfers[4].

[2] Six countries currently have TFCA agreements: Bangladesh, Belize, El Salvador, Panama, Peru, and the Philippines. These agreements, which were adopted between 2002 and 2004, generate $70 million for tropical forest conservation in these countries, and are designed to improve sustainable forest conservation as scientific and managerial capacities. For instance, the Republic of Philippines obtained $8 million over 14 years to implement a mangrove conservation program.

[3] http://www.wri.org/stories/2009/01/ecuador-proposes-leaving-oil-untapped-protect-forests-and-people

[4] http://www.independent.co.uk/environment/climate-change/million-acres-of-guyanese-rainforest-to-be-saved-in-groundbreaking-deal-801239.html

In 2005, Costa Rica and Papua New Guinea submitted a proposal for a multilateral REDD policy: countries that agree to reduce their deforestation and forest degradation below a baseline would be entitled to compensation from developed countries, either in the form of monetary transfers or through tradable allowances in proportion to avoided deforestation. This proposal endorses for the first time that idea that forests should be considered both by developing countries and developed countries as a global public good and that the participation of all countries should be sought. After a preliminary examination of the REDD proposal, international negotiations on avoided deforestation resumed in 2007 at the 13th COP to the UNFCC in Bali, which focused on the urgent need to mitigate the impact of deforestation on climate change. However, no consensus has yet been reached on the best mechanism and payment rules. There is disagreement among the group of developing countries, according to their capacity to reduce deforestation, and among developed countries. Two broad approaches for REDD are currently under examination. One, the "input-based" option, seeks to manage the drivers of deforestation by paying countries that adopt deforestation mitigation policies. The other, the output-based option, pays countries once results in terms of avoided deforestation (either at national or at project level) can be observed and certified. The advantage of the first option is that deforestation levels do not need to be measured and that developed countries can to some extent impose their preferred anti-deforestation strategies on deforesting countries. The latter option guarantees that the target of avoided deforestation is reached before payments are made. However, unless payments are scheduled over a long time span or unless a specific mechanism is set up to sanction countries that defer deforestation activities only to resume them after payments have stopped, there is a risk REDD gains in terms of avoided deforestation will only be temporary (this is called the permanence issue). Another risk associated with the REDD mechanisms is leakage, the translocation of deforestation activities to areas outside the abatement area, leading to intensified deforestation either in other regions of the same country or in third countries that are not part of the REDD system.

Together with the increasing awareness that the implementation of REDD could involve very large North-South transfers –beyond current ODA flows – these drawbacks have led a number of developed countries to adopt a cautious attitude and to examine alternative approaches to the deforestation problem. For example, the European Union (EU), which also wishes to protect its new carbon market, is promoting other solutions, such as measures to reduce illegal logging and illegal trade of forest timber and products, and certification programs.

2.2. Synergy effects of international policy instruments

This history of negotiations shows that several types of international instruments have been envisaged to try to curb the global rate of deforestation. Five broad types of instruments can be distinguished: (i) trade instruments that sanction illegal logging; (ii) forest stewardship certification, with the expectation that certified products will meet a greater international demand and reach a higher price than non-certified products; (iii) debt-for-nature swaps; (iv) input-based REDD payments and (v) output-based REDD payments. The net effects of these policy instruments are not straightforward. As shown in table 1, the direct impacts are linked to the way instruments and conditionalities are designed. However these international instruments have indirect longer term impacts on macroeconomic variables of recipient countries and on the structure of incentives. If massive payments are made, they will increase net national income. They may improve the investment capacity of rural communities – if the money received trickles down to them – or the investment capacity of the state. They may contribute to greater foreign exchange earnings and to debt alleviation. However, the effects of these macroeconomic changes on deforestation are less predictable. They can either reinforce the initial effort towards reducing deforestation, or mitigate it.

For instance, the macroeconomic optimization model of Kahn and McDonald (1995) reveals that in order to pay back their debt, developing countries tend to adopt short term policies that work against conservation. These authors demonstrate theoretically that debt-for-nature swaps have double positive synergy effects on deforestation, because they impose the creation of conservation areas by agreement, and simultaneously relieve the pressure of debt. In a similar way, we argue that the net effect of incentive transfers on forest area can either be positive or negative depending on the way they indirectly affect drivers of deforestation. For example, large REDD transfers can actually relieve pressure on forest resources if they are allocated to poverty alleviation programs in rural forested area (Karsenty, 2008). However, these funds can also be used to promote activities that compete with forest cover, such as the development of infrastructure (roads across forests) or the expansion of cash crops at the expenses of forest land. In such case, the indirect impact of North-South transfers might be an acceleration of deforestation in the medium and long term, annihilating short term efforts to avoid deforestation, that have to be demonstrated by countries in order to become eligible.

Table 1: Direct and indirect impacts of international instruments

International policies	Direct impact expected	Indirect economic impact expected	Effect on deforestation?

Trade sanctions on illegal logging Forest stewardship certification programs Debt-for-nature swaps Input-based REDD payments Output-based REDD payments	Higher costs for illegal loggers Higher international demand/price for certified products Expansion of protected areas Compensation for opportunity costs of avoided deforestation	Greater foreign exchange earnings Debt alleviation Greater investment capacity for rural communities Greater state investment capacity	Positive? or negative?

Given the range of international policy instruments tabled in current international negotiations, there is a need for a better assessment of their direct and indirect impacts on the drivers of deforestation. Most economic models of deforestation try to identify drivers of deforestation to explain the growing pressure on forest cover (Kaimowitz and Angelsen, 1998). However, few econometric studies have attempted to link their conclusions with international policies.

2.3. Deforestation patterns and relative forest endowment

Another issue at stake in current multilateral negotiations on forest is the need to better tailor international policy instruments to the diversity of so-called “national circumstances”. All tropical countries obviously do not have the same past rate of deforestation nor the same need for future economic and demographic development. It is common knowledge that one-size-fits-all solutions are inappropriate because deforestation drivers vary by country and region. On the other hand, although domestic policy options to reduce deforestation can vary, there is a real need to design the most inclusive international scheme as it is the best insurance against leakage.

Our objective was thus not to identify the best policy option for each country but rather to analyze whether it would be useful to design better-adjusted international instrument packages for different types of deforesting countries. To this end, we conducted a country-level panel data analysis linking the rate of forest area (capturing the deforestation phenomenon) to variables that measure the direct and indirect effects of international instruments.

Most econometric analyses of deforestation conduct pooled estimations (Combes Motel et al., 2009; Allen and Barnes, 1997; Shandra and al, 2008; Bhattarai and Hammig, 2004) or cluster estimations by continents (Cropper and Griffiths, 1994; Koop and Tole, 1999; Bhattarai and Hammig, 2001; Culas, 2007). Bhattarai and Hammig (2001) justify the choice of the continent division claiming that a continent “*provides a comparable set of environmental and* *economic conditions across a wide geographic area*". However, climate or geographic location and characteristics can be captured through a fixed-effect panel-data model, and it would be inaccurate to argue that the response of countries to the deforestation drivers will be the same among countries just because they belong to the same continent. Moreover, segmentation by continent does not take the "forest transition" phenomenon into account, which is essential in understanding deforestation dynamics. Forest transition theory argues that it is unlikely that massive deforestation will be maintained over time, as the opportunity costs of deforestation increase with increased forest scarcity (Ewers, 2005; Karsenty, 2008; Damette and Delacote, 2008). Rudel et al. (2005) argue that the feeling of forest scarcity reduces incentives to deforest and can even lead to reforestation, as in China or India. In contrast, Brazil, Cameroon and Indonesia continue to deforest because of the abundance of their forests. We therefore chose to estimate three models for three average levels of forest endowment. We stick to the clustering chosen by FAO: countries with low forest endowment[5] with 10 to 30% of forest cover (LE group), medium endowment countries i.e. 30 to 50% of forest cover (ME) and countries with high forest endowment i.e. more than 50% of forest cover (HE). The HE group corresponds to the pooling of two FAO categories, in order to have approximately the same number of countries in each group.

3. Data and model specifications

3.1. ***Econometric Model***

Early econometrics studies on drivers of deforestation were cross-sectional models, because insufficient data was available for time-series analysis (Kaimowitz and Angelsen, 1998). Koop and Tole (1999) underlined that a robust analysis of deforestation required panel data analysis. More recent studies therefore mobilized panel data (Cropper and Griffiths, 1994; Koop and Tole, 1999; Culas, 2007; Combes Motel et al., 2009). Except for Shandra et al. (2008) and Combes Motel et al. (2009), who used recent data, all other available studies are based on fifteen-year-old data sets, thus limiting their interpretative powers for recent years during which the international context has changed quite dramatically.

Our contribution is to use a recent data base covering the period from 1990 to 2005: it is one of the first econometric analyses to capture deforestation dynamics during the 2000s. All developing countries with more than 10% of forest cover are included, except for four

[5] Forest endowment is the percentage of forested area of the total area of a country

countries with an incomplete data set[6]. Equatorial Guinea was also excluded from the sample as an outlier because its income per capita is three times the average. Our panel data (table 2) includes a sample of 56 countries divided into three sub-samples based on their initial forest endowment relative to their total area. There are 16 countries in the LE group, 18 countries in the ME group and 22 in the HE group. We conducted a Chow test to compare the pooled model (56 countries) with the same model estimated for the three separate samples (HE, ME and LE): the F-statistics is equal to 32.62 above the F-value of 2.43, therefore the coefficients obtained by grouping countries according to their relative forest endowment was significantly different from those in pooled model.

Table 2 – 56 countries included in the model, by continent and by endowment group

Low forest endowment (LE)	**Medium forest endowment (ME)**	**High forest endowment (HE)**
16 countries	18 countries	22 countries
Latina America		
3 countries	5 countries	10 countries
Argentina El Salvador Chile	Costa Rica Ecuador Guatemala Mexico Nicaragua	Belize Bolivia Brazil Colombia Guyana Honduras Panama Paraguay Peru Venezuela, Bolivarian Rep.
Africa		
10 countries	8 countries	8 countries
Benin Burkina Faso Madagascar Mali Mozambique Nigeria Sudan Swaziland Togo Uganda	Angola Central Af. Rep. Cote d'Ivoire Ghana Malawi Senegal Tanzania Sierra Leone	Cameroon Congo, Dem.Rep. Congo, Rep. Guinea-Bissau Gabon Guinea Zambia Zimbabwe
Asia and Oceania		
3 countries	5 countries	4 countries
China India Vietnam	Indonesia Nepal Philippines Sri Lanka Thailand	Cambodia Lao, People's Dem. Rep. Malaysia Papua New Guinea

The best data on natural forest cover[7] are collected by the World Resources Institute but are unfortunately only available for three years (1980, 1990 and 1995) (Bhattarai and Hammig, 2004). The FAO provides data on forests and woodlands, with natural and planted trees, including land cover that has been cleared but that will be reforested in the near future. Only forest plots whose area exceeds 0.5 hectare and whose canopy covers at least 10% of the surface area are included. We used the forest cover data from the 2005 FAO Forest Resources Assessments (FRA). This new data base is much more reliable than the previous FAO data

[6] Botswana (LE country), Liberia (ME country), Myanmar (HE country) and Suriname (HE country)
[7] this is the natural forest cover observed by the Landsat satellite, later verified using GIS and field observations and compiled by the Global Environmental Monitoring Systems (GEMS) and FAO.

base (FAO FRA of 1980 and 1990 used in the majority of previous studies) based on old inventories and extrapolated from a single data point with a deforestation model that only depended on population growth. The 2005 FAO FRA contains information collated from more countries and territories (229) for three points in time (1990, 2000 and 2005) and improved by the use of satellite images, "regular contact, expert consultations, training for national correspondents and ten regional and sub-regional workshops" (FAO, 2005).

We can therefore reasonably assume that the 2005 FAO FRA is the best international data set available. We used the relative forest endowment of each country as our dependent variable. This corresponds to the percentage of the total area of the country under forest. We tested several specifications for the model and the most satisfactory one was the log-log specification. It enables us to interpret estimated coefficient as elasticities.

$$Log\left(farea_{it}\right) = \alpha_i + \sum_{k=1}^{K} \beta_k Log\left(X_{kit}\right) + u_{it}$$

Where $i = 1,...,N$ countries and $t = 1,...,15$ periods; $farea_{i,t}$ is the dependant variable; α_i is the intercept term for country i; β_k, $k=1,...,K$ are the coefficients to be estimated for the K explanatory variables (table 3)[8].

The F-test shows the rejection of the simple pooled regression for a panel specification. A Hausman test applied to all samples allowed us to accept the fixed effect model at a risk of 5%. The Breush-Pagan test confirmed the existence of heteroskedasticity in our model. The model was thus estimated by fixed-effect formulation with correction for heteroskedasticity using the Eicker-White matrix.

We distinguished two types of explanatory variables: the first set of variables captures the effects of deforestation drivers, mainly competition for land; the second set of variables is included to measure the indirect impact of international policy instruments.

Descriptive statistics of regression variables are presented in appendix 1. The highest deforestation rate was observed in the ME country group. It is worth noting that the LE group had a positive reforestation rate during the study period. This is due to reforestation in countries like China, India, Chile, Swaziland and Vietnam. However, when China was left out of the sample, the average forest area in the LE group declined. In the ME group, the Ivory Coast also reforested steadily over the 15 years of the study period and Costa Rica started

[8] We obtained the same regression result (except for the estimated intercept value) when we used the forested area as dependent variable instead of the relative forest endowment (due to the log-log specification).

reforestation in 2001; in the HE group, Guyana and Belize had a rate of deforestation close to 0.

Table 3 Definition and description of explanatory variables

<table>
<tr><th colspan="3">Explanatory variables</th><th>X_i</th><th>Unit</th><th>Dataset</th><th>Expected sign</th></tr>
<tr><td rowspan="4">Competition for land</td><td colspan="2">Rural population</td><td>POPRUR</td><td>Rural population/total population</td><td>FAO</td><td>Negative</td></tr>
<tr><td colspan="2">Export value of forest products</td><td>XFOR</td><td>Current millions $US</td><td>FAO</td><td>Negative</td></tr>
<tr><td colspan="2">Export value of agricultural products</td><td>XVAL</td><td>Current billions $US</td><td>FAO</td><td>Negative</td></tr>
<tr><td colspan="2">Agricultural added value</td><td>AGVAL</td><td>Current 1 000$US per square kilometers</td><td>WB</td><td>Negative or positive</td></tr>
<tr><td rowspan="4">Potential feedback effects on deforestation</td><td rowspan="2">Environmental Kuznets Curve</td><td>GDP per capita</td><td>GDPC</td><td rowspan="2">Current $1000 US</td><td rowspan="2">WB</td><td>Negative</td></tr>
<tr><td>GDP per capita squared</td><td>GDPC²</td><td>Positive</td></tr>
<tr><td colspan="2">External debt, total</td><td>DEBT</td><td>Current million $US</td><td>WB</td><td>Negative</td></tr>
<tr><td colspan="2">Terrestrial areas protected</td><td>PA</td><td>Terrestrial areas protected/ total area per country</td><td>United Nations</td><td>Positive</td></tr>
</table>

3.2. Explanatory variables

3.2.1. Deforestation drivers: competition for land

Population pressure and poverty are considered to be one of the main drivers of environmental degradation. This hypothesis is supported by the neo-Malthusian theory (Shandra et al., 2008; Cropper and Griffiths, 1994; Bhattarai and Hammig, 2004). Population grows more rapidly than means of subsistence, and people consequently look for new areas in which they can respond to the increasing needs in food and fuelwood. Shandra et al. (2008) point to the role of growing populations of small-scale farmers and shifting cultivators in the sharp increase in deforestation. In Bhattarai and Hammig (2001) and Shandra et al. (2008), the population growth rate and rural density are included in a deforestation model. Their results show that rural population pressure - and not overall population growth - is a significant factor contributing to deforestation. This is a result found also by Barbier and Burgess (1997), Combes Motel et al. (2009), and Cropper and Griffiths (1994) only for Africa. Consequently, we included rural population as an explanatory variable in our model.

Forest cover is threatened by agricultural expansion, wood extraction (fuelwood, commercial, charcoal etc.) and the extension of infrastructure (Kaimowitz and Angelsen, 1998). Incentives to clear forest for conversion to agriculture are measured in existing econometric models of deforestation by proxies of agriculture profitability such as exports of agricultural commodities (Culas, 2007; Combes Motel at al., 2009), instability of agricultural commodity export unit value (Combes Motel et al., 2009), agricultural value added (Bhattarai and Hammig, 2004) or average farm yield. Bhattarai and Hammig (2004) found that improvements in agricultural productivity reduced the pressure to convert forestland to agricultural use. Combes Motel et al. (2009) showed that the higher the price of agricultural commodities, the higher the deforestation rate. When prices subsequently decreased, the deforestation rate nevertheless remained high. The links between agricultural productivity and deforestation are not easily disentangled. Angelsen and Kaimowitz (2001) devoted an entire book to measuring how technological change in agriculture can affect tropical forest cover. According to these authors, there are two broad responses: on the one hand, a 'win-win' situation where, at the macro-scale, the increase in agricultural yields leads to "economic development and growth, which, in turn, is associated with other changes that limit deforestation" and, at the micro-scale, technological change enables intensification rather than expansion of arable land. On the other hand, there is a 'win-lose' situation if farmers are encouraged to "cultivate more land since farming has become profitable". To measure the competition between agriculture and forest, we introduced two variables in our model: the added value per square kilometer generated by the agricultural sector; and the export value of agricultural commodities. The second variable enabled us to measure deforestation due to forests conversion for export agricultural products.

Wood extraction pressure is usually measured by roundwood production (Barbier and Burgess, 1997) or by the price of tropical logs (Cropper and Griffiths, 1994, who found a positive relationship between the price of tropical logs and deforestation only in Latin America). We used the export value of timber products[9], which provides an estimation of the revenues generated by logging. It is obvious that this variable is insufficient because it does not measure illegal logging[10] nor the volume of trees harvested for fuelwood but it is the best available estimator for wood extraction incentives.

The causality relationship between export values of forest and agricultural products and deforestation can be ambiguous since export values can also be explained by deforestation. To

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[9] Timber products cover roundwood, fuelwood and charcoal, industrial roundwood, sawnwood, wood-based panels, pulp, paper and paperboard (FAO website)

[10] The FAO (2005) reported that in most of countries where illegal logging occurs, the volume of illegally harvested timber exceeds the amount of official annual timber harvested. In this way, we can postulate that illegal logging strengthens the impact of the correlation between rate of deforestation and the value of exports of forestry products.

avoid this endogeneity issue, we introduced a one-year lag for these two variables in our model.

Several authors have demonstrated that the quality and the robustness of institutions (in particular security in property rights) can contribute to a reduction in deforestation behaviour and ensure more sustainable forest management (Culas, 2007; Bhattarai and Hamming, 2004; Deacon, 1994). Following Bhattarai and Hamming (2004), in our model we added two additional explanatory variables, a political rights index and civil liberties index, both obtained from the Freedom House database. However, these variables were not significant, probably because they are too broad in scope to adequately capture the complex issue of collective rights that often prevail in forests. We therefore decided ultimately to drop these variables from our model.

3.2.2. Explanatory variables with likely feedback effects on deforestation process

3.2.2.1. National income

One of the main findings of most studies is the correlation between economic growth and the rate of deforestation, confirming the general empirical result of the environmental Kuznets curve (EKC): an inverted U-shaped relationship between environmental degradation and economic growth. Cropper and Griffiths (1994) and Bhattarai and Hammig (2001) obtained a hump-shaped relationship between GDP *per capita* and rate of deforestation in Africa and in Latin America, while Koop and Tole (1999) observed an EKC for deforestation only in Asia and Africa. The only two studies where a pooled sample was used (Combes Motel et al., 2009; Bhattarai and Hammig, 2004), confirmed the existence of an EKC relationship.

The general explanations are that low-income countries clear forests to increase arable area and fuelwood. Higher levels of income are often associated with greater rural density, which in turn accelerates the pace of deforestation. However, beyond a given level of income (the so-called “turning point”), deforestation starts declining: higher income enables technical change and modernization of agriculture and makes investments in industrial activities more profitable. It relieves the pressure on forest (Bhattarai and Hammig, 2001). Food and energy consumption also changes: “fuelwood energy predominates during early stages of development but coal and petroleum-based fuels become more important during later stages, thereby reducing further forest conversion pressure” (Bhattarai and Hammig, 2004). Finally, the wealthiest countries start investing in the protection of biodiversity and natural resources because there is greater demand for environmental services and amenities (Mills, 2009).

To test the EKC hypothesis for forest, we expect a negative coefficient for the GDP *per capita* term, while we introduce a quadratic income term that should have a positive coefficient in the regression model.'

3.2.2.2. Debt

We introduced a variable measuring the need to earn foreign exchange in order to repay debt. Total external debt may be an explanatory variable of deforestation, because developing countries often rely on "the export of whatever available natural resources may be in demand on the world market" (Shandra et al., 2008) to pay back their international debt. We expected a negative sign for the correlation between debt and deforestation, thus supporting the synergy effect of debt-for-nature swaps. Kahn and McDonald (1995), Bhattarai and Hammig (2001) found that debt is one of the main factors leading to excessive deforestation, and confirmed the importance of debt management in the tropical deforestation process.

3.2.2.3. Protected areas

To the previous macroeconomic variables, we added a variable measuring the total terrestrial protected area. These are areas of land especially dedicated to the preservation of biodiversity. In 2008, the United Nations Environment Programme counted about 17 million[11] square kilometers of marine or terrestrial protected areas, of which 12.4% are forests[12]. We used the database built by the UN data for Millennium Development Goals[13] to measure the consequence of the establishment of protected areas on deforestation rates. Although we intuitively expected a positive correlation between forest area and protected area, we wanted to check whether leakage issues within countries might in fact increase the net rate of deforestation by intensifying deforesting activities outside the conservation area.

4. Results and policy recommendations

4.1. Regression results

Results of estimations are shown in table 4 for the whole sample (pooled results) and for the three groups: LE, ME and HE. For the four regressions, the within R^2 was between 0.24 and 0.62, confirming the reasonably good explanatory power of our model. Splitting the pooled

[11] equivalent to 4% of the total area in the world
[12] http://www.iucn.org/about/work/programmes/forest/fp_our_work/fp_our_work_oaw/fp_our_work_fpa/
[13] http://mdgs.un.org/unsd/mdg/Data.aspx

sample into three country groups according to forest endowment improved the significance of explanatory variables[14].

Results shown in table 4 enabled us to evaluate the possible complementary or substitution effects of international policy instruments to reduce deforestation. We observed that indirect unforeseen effects vary across the three groups. This analysis helped us formulate recommendations for differentiated policies designed to address the specificities of each country group.

Almost all estimated parameters were statistically significant in the LE and ME groups, whereas the picture that emerged for the HE group was less clear, as few variables were significant. We tested various model specifications and several other explanatory variables but, whatever the model used, we were unable to identify a better model. It seems that the deforestation trend in the HE group is relatively independent of changes in deforestation drivers. Our hypothesis to explain this surprising result is that the high relative endowment in forest locks this group in a development path that is largely supported by the exploitation of forest resources or the conversion of forests into farmland, without enough economic alternatives to enable the country to switch to a different development pattern. Consequently, except for debt relief policies, these countries are relatively insensitive to international incentives.

Another general result is that greater indebtedness in all country groups leads to more deforestation, according to the negative and statistically significant estimation parameter of variable DEBT. As already stated in the discussion on model variables, indebted countries are tempted to repay their debt by increasing the export earnings of agricultural and forest products. The forest-debt elasticity is –0.040 in the LE group while it is –0.075 in the ME group, demonstrating that international debt alleviation can be a truly effective international policy to curb global deforestation.

[14] The model for LE group was also estimated without China and India to control for possible size effects. Since results were robust, we maintained these two countries in our sample

Table 4 – Estimation results

	Pooled *Log(farea)*	**LE** *Log(farea)*	**ME** *Log(farea)*	**HE** *Log(farea)*
Log(POPRUR)	-0.270*** (-9.48)	-0.5431*** (-6.85)	-0.289*** (-7.55)	-0.172*** (-4.71)
Log($XFOR_{T-1}$)	-0.00798*** (-4.15)	-0.00344 (-0.75)	-0.00396* (-1.93)	-0.00111 (-0.39)
Log(XAG_{T-1})	-0.0114*** (-2.63)	-0.00697 (-0.70)	-0.0332*** (-4.50)	-0.00470 (-1.03)
Log(VAAG)	-0.0156 (-1.10)	-0.0943** (-2.30)	0.0635*** (3.88)	-0.00750 (-0.39)
Log(GDPC)	0.0100 (0.64)	0.103*** (3.57)	-0.0872*** (-4.55)	-0.0183 (-0.91)
Log(GDPCS)	-0.00222 (-0.59)	-0.000733 (-0.11)	0.0180*** (3.36)	-0.000231 (-0.06)
Log(DEBT)	-0.0482*** (-4.39)	-0.0393* (-1.94)	-0.075*** (-4.16)	-0.0277** (-2.41)
Log(PA)	-0.00461 (-0.75)	0.257*** (7.44)	-0.106*** (-3.17)	-0.0143*** (-2.64)
CONS	3.285*** (18.65)	1.503*** (4.29)	4.036*** (13.08)	-1.033*** (51.02)
N	837	237	270	330
R^2	0.28	0.47	0.62	0.24

T statistics in parentheses
*p<0.10, ** p<0.05, ***p<0.01

4.2. Results and policy recommendations for countries in the low endowment group

The coefficient of GDP *per capita* is positive and statistically significant, although the quadratic term is not. In this group, an increase in income reduces the pressure on forest cover: an increase of 10% in GDP per capita can lead to an average increase in forest area of 1.1%. Consequently, favoring economic growth should indirectly contribute to forest protection. This result, which concerns a group of countries in which the average GDP per capita is very low (1147 $/capita) contradicts the EKC hypothesis of an initial degradation of natural resources with an increase in income. Some countries in the LE group already have a clear reforestation policy. This result indicates that the REDD mechanism, be it output-based payments or input-based payments, will be effective by helping to increase the national income of recipient countries.

The deforestation rate in the LE group appears to be mainly driven by rural population pressure (which increases demand for fuelwood) and gains in agricultural productivity: competition between forest and agricultural lands concerns staple crops more than export crops (the parameter for XAG is not significant).

Protected area policies have a positive and strong impact on forests with a forest-protected area average elasticity of 0.25. One of the first explanations is that the priority in LE countries is protection of the forest since forests are already scarce. For instance, out of the 78 protected areas in Burkina Faso, 63 are dedicated to forests[15]. The second reason is that it is easier to create alternative activities for people who are forbidden to exploit protected forest areas, and the issue of leakage is therefore less crucial than in other groups. Domestic or international policies against deforestation should therefore focus on offering alternatives for fuelwood to rural populations, favor the intensification of food crops to spare forest land and promote the establishment of forest protected areas. The REDD program can be expected to be very effective, whether implemented at the national level or at the project level.

4.3. *Results and policy recommendations for countries in the medium endowment group*

The ME group is the only group in which we confirmed the environmental Kuznets curve for deforestation, with highly significant estimated parameters both for GDPC and GDPC *squared*. This indicates that the rate of forest area in the LE group first declines when GDP *per capita* increases, then, for higher levels of income, beyond a turning point, the deforestation rate diminishes. This result at least partially confirms the results of other studies (Combes Motel and al., 2009; Bhattarai and al., 2004; Culas 2007; Cropper and Griffiths, 1994).

Lind and Melhum (2007) argue that a significant quadratic term is not sufficient to confirm the non-linear effect. The turning point must be contained in the data range and tests on slopes at the beginning and the ending of the interval must confirm the U-shape (Couttenier, 2008). We ran the U-shape test proposed by Lind and Melhum, (2007) based on a Sasabuchi test (Couttenier, 2008). Results are given in table 5.

Table 5 - Test for U-Shape (Lind and Melhum (2007))

Log(GDP)	**ME countries**
Interval	[-2.130; 2.008]
Slope at Lower Bound	-0.164
Slope at Upper Bound	-0.0149
Sasabuchi test for U-shaped	Extremum outside the interval
Turning Point	2.420
95% confidence interval for extreme point (Fieller method)	[1.152; 6.290]

The turning point is outside the interval, corresponding to a GDP per capita of US$ 11 250 (in 2005, the higher GDP *per capita* in the ME group is at $US 7450 for Mexico). A GDP *per capita* of US$ 11 250 is plausible[16] but it is unlikely that one of the ME countries will reach it

[15] http://bch-cbd.naturalsciences.be/burkina/bf-eng/index.htm
[16] It is the GDP per capita of South Africa in 2008

in the near future. Therefore since GDP growth accelerates deforestation in ME countries, a REDD program with output-based payments is preferable to a REDD program with input-based payments, i.e. payments should be made only on the basis of certified avoided deforestation. To avoid the issue of non permanence, the international community will have to be particularly cautious either by deferring part of the payment over the longer term or by re-imposing strict deforestation conditions for the next period payments.

We observed that the deforestation rate in ME countries is worsened by rural population pressure, as in the LE group. However, competition between forest conservation and the temptation to increase agricultural and forestry products exports is significant. Consequently sustainable forest management and certification of agricultural products are essential policies to reduce deforestation.

In this group, as in the HE group, we observe a surprising negative elasticity between the forest cover rate and protected area (- 0.29). This result can be explained by the phenomenon of internal leakage: the creation of a new forest conservation area leads to intensified extraction in neighboring areas, mainly because forest users are driven out of their traditional area of activity without sufficient monetary compensation or economic alternatives. Their only option is thus to start deforesting unprotected areas, often at a greater rate to generate more revenue and to be able to re-invest. The establishment of forest conversion areas must therefore be implemented with careful accompanying measures and adequate local development projects.

5. Conclusion

Our results confirm that deforestation patterns are strongly related to forest endowment: indeed, we demonstrate that drivers of deforestation do not have the same impact –in sign and intensity – in highly forested countries as in countries with a low percentage of forests. Although this has often been reported in qualitative analysis of deforestation dynamics, this is the first econometric analysis to confirm this intuition with a full panel of tropical countries. Of course, these results should be interpreted with caution since they only capture average trends and use an imperfect database.

Our analysis provides a better understanding of the drivers of deforestation at the macroeconomic level, and should help draw up policy recommendations for the design of international policy instruments.

We illustrate that beyond the outcomes resulting of the conditionality of policy instruments (direct impact), feedback effects on deforestation occur through changes in deforestation drivers. Some international policy instruments are better suited for particular groups of countries, while other instruments should be avoided in certain countries. Debt relief policy is effective in all three groups. In the low endowment group, an efficient policy package should include the expansion of protected forests, intensification of staple food production, and the setting up of a REDD mechanism. The package differs from that recommended for the medium endowment group where the REDD mechanism should favor output-based payments, and should avoid project-level implementation to contain leakage; and forest stewardship certification should be encouraged and subsidized. International policy instruments would be less effective –at least in the short term – for the high endowment group. This pleads in favor of longer term solutions involving long-term conditional financing commitments between the international community and these particular deforesting countries.

Ideally, policy interventions to curb deforestation should be tailored to local specificities but there is a risk that favoring small-scale projects will not create the necessary impetus by the international community to come to grips with the deforestation problem. There is therefore a true value added in a collective international effort, even if it results in imperfect policy instruments. Our work should help improve the fit between international policies and the needs of groups of countries by taking into account the "national circumstances" as advised in REDD discussions.

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Appendix 1 – Descriptive statistics of variables in the study

Variable		Pooled	LE	ME	HE
FAREA	**Mean**	**41.32**	**20.61**	**38.05**	**59.06**
(forest areas/total	**S.D.**	**18.19**	**6.90**	**8.15**	**10.85**
*area*100)*	Min	6.79	6.79	23.13	27.35
	Max	81.91	38.98	61.20	81.92
Deforestation rate	**Mean**	**0.00755**	**0.00621**	**0.0104**	**0.00620**
	S.D.	**0.0104**	**0.0154**	**0.00735**	**0.00680**
	Min	-0.0258	-0.0258	-0.00149	0
	Max	0.0492611	0.04926	0.0320	0.0347
PA	**Mean**	**15.66**	**9.48**	**18.45**	**17.87**
(protect areas/total	**S.D.**	**12.29**	**8.012**	**8.68**	**15.43**
*area*100)*	Min	0.0049	0.0049	2.59	0.75
	Max	71.34	26.09	38.36	71.35
GDPC	**Mean**	**1.342**	**1.147**	**1.171**	**1.624**
(Current 1 000$US)	**S.D.**	**1.559**	**1.799**	**1.327**	**1.506**
	Min	0.0849	0.0978	0.119	0.0849
	Max	8.281	8.281	7.447	6.714
$GDPC^2$	**Mean**	**4.227**	**4.543**	**3.124**	**4.900**
	S.D.	**9.330**	**12.651**	**7.396**	**7.710**
	Min	0.00721	0.00956	0.0141	0.00721
	Max	68.569	68.570	55.456	45.078
POPRUR	**Mean**	**.0412**	**0.0619**	**0.0562762**	**0.0137**
(Rural population/	**S.D.**	**0.0517**	**0.0628**	**0.0558**	**0.0126**
total population)	Min	**0.000792**	**0.00120**	0.00305	0.000792
	Max	**0.247**	**0.246**	0.247	0.0619
VAAG	**Mean**	**32.267**	**25.230**	**40.967**	**30.268**
(Current 1 000$US	**S.D.**	**35.6103**	**25.908**	**38.635**	**37.723**
per square	Min	0.470	1.440	0.470	1.538
kilometers)	Max	196.92	116.091	172.765	196.922
XAG	**Mean**	**1766.035**	**2 315.78**	**1 721.022**	**1 403.05**
(Current billions	**S.D.**	**3530.229**	**4 188.948**	**2 506.939**	**3 679.21**
$US)	Min	1.156	26.075	1.156	3.35
	Max	30 802.96	20 524.24	12 276.63	30 802.96
XFOR	**Mean**	**353.3244**	**349.465**	**351.330**	**357.762**
(Current millions	**S.D.**	**990.3407**	**964.964**	**1 090.171**	**923.336**
$US)	Min	0	0	0.01	0.004
	Max	6 852.669	6 852.669	5 517.412	5 499.522
DEBT	**Mean**	**24 273.44**	**30 398.33**	**26 537.23**	**17 966.78**
(Current million	**S.D.**	**44 333.47**	**48 861.97**	**43 744.04**	**40 509.8**
$US)	Min	142.733	259.561	698.507	142.733
	Max	281 612.1	281 612.1	171 161.7	244 107.7

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