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

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SUMMARY

Safeguarding the tropical rainforest 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 the deforestation rate in tropical countries. Debt-for-nature swaps, and certification of sustainable forest manangement have been implemented by NGOs. Sates are currently negotiating on 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 return the drivers of deforestation. This 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 conduct a panel-data analysis over the 1990-2005 period and we show that a more relevant clustered analysis for tropical forest countries should be based on relative forest endowment. On the basis of econometric results, we can recommend a differentiation of policy instruments according to the relative forest abundance of each country. Debt reduction programs contribute to the reduction of deforestation in all countries. Forest-abundant countries are locked into a development path based on forest overexploitation making them little responsive to incentive measures. In countries with average forest endowment, we recommend an output-based REDD implemenation, whereas in countries with low forest cover, input-based as output-based REDD mechanisms should be more efficient.

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1. Introduction

Tropical deforestation is not a recent phenomenon but it has become a growing concern in recent times because of its global environmental impacts. The forest area has lost 13 million hectares on average per year (excluded reforestation area) between 1990 and 2005 (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 which could induce tropical forest rich countries to curb their deforestation activities. Deforestation is mainly due to the expanssion of arable land, the need of local population for fuelwood (Chomitz, 2007) and the dependance on earn foreign exchange earnings: trade of tropical wood 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 not prepared therefore to reduce their deforestation activities without compensation. They argue that a global solution to the deforestation issue must include a North-South transfer scheme compensating 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[2] scheme are currently on the negotiation table. They can be tropical timber trade measures 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 on timber price of trade

[2] Reduced Emissions from Deforestation and Degradation

intervention; 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, foreign exchange earnings etc. These effects –which are often overlooked in policy-making discussions- can either reinforce the direct impact, or 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: it provides a country-level panel data analysis of the main drivers of deforestation which helps in turn to forecast the direct and indirect impacts of policy instruments proposed by the international community. Econometric estimations are made with a data base covering the 1990- 2005 period, allowing us to capture the most recent deforestation dynamics. In contrast with other available studies which often provide estimation results per continent, we show that a more relevant cluster analysis should be 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 effect by indirectly creating new incentives to deforest. Debt relief seems to be the only policy efficient for all types of countries.

The paper is organized as follows. Section 2 is dedicated to a historical review and a description of policy instruments used at the international level to limit deforestation. Data and model specifications are presented in section 3. Section 4 analyses results and draws recommendations on the adequation of international policy instruments to countries' characteristics.

2. International policy instruments to reduce deforestation

2.1. Historical perspective

Although a genuine multilateral negotiation only started in 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 70th and several policies have already been tested with mixed success.

As early as the 1970s, developed countries had pressed the South to implement sustainable forest management. However, developing countries, gathered in the group of 77 (G77), required that a global forest fund be created to finance "opportunity cost foregone", arguing that developed countries shared responsibilities 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 to include afforestation and reforestation in the Clean Development Mechanisms (CDM), as projects of emissions reduction in developing countries. But it left aside the crucial issue of deforestation.

In face of the lock-in of 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, enables developing countries to reduce their debt while increasing their budget for conservation activities: NGOs negotiate outside international official agreement the reduction of the debt of developing countries with international banks, and in return developing countries commit to an environmental conservation agreement. Another initiative from NGOs is the Forest Stewardship Council (FFC), which promotes timber product certifications in order 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, the United States enacted in 1998 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, internet website)[3]. Moreover, outside actual international negotiation or current bilateral agreement, developing countries have submitted "groundbreaking deals" to protect rainforest to some developed countries. For

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

example, the government of Ecuador in 2007 declared to be ready to renounce to the oil resource under Yasuni National Park if international community compensated the loss of revenues forgone to oil exploitation[4], while the same year, Guyana offered to Britain the management of one million acres of rainforest in exchange of financial transfers[5].

Costa Rica and Papua New Guinea submitted a proposal in 2005 for a multilateral REDD policy: countries accepting to reduce their deforestation and forest degradation beyond a baseline would be entitled to compensations from developed countries, either in the form of monetary transfers or through tradable allowances proportional to avoided emissions. This proposal endorses for the first time that forests should be considered both by developing countries and developed countries as a global public good and participation of all countries should be sought. After a preliminary examination of the REDD proposal, international negotiations on avoided deforestation have resumed in 2007, during the 13th COP to the UNFCC in Bali, which focused on the emergency to mitigate the impact of deforestation on climate change. However, there is no consensus yet on the best mechanism and payment rules. Dissensions exist both 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 : the “input-based” option seeks to manage the drivers causing deforestation by paying countries accepting to adopt deforestation mitigation policies; 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 former 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 to deforesting countries. The latter option garantees that the target avoided deforestation is attained before payments are made. However, unless payments are sheduled over a long time span or unless a specific mechanism is set in place to sanction countries which would defer deforestation activities to resume them in the after-payment period, there is a non negligible risk of non permanence of the REDD gain in terms of avoided deforestation. Another risk associated with the REDD mechanisms is leakage, the translocation of deforestation activities to areas outside the abatement place, leading to

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

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

intensified deforestation either in other regions of the country or in third countries which would not be part of the REDD system.

These drawbacks together with the increasing awareness that the implementation of REDD could involve very large North-South transfers –beyond current ODA flows – have led a number of developed countries to adopt a cautious attitude and to examine also alternative approaches to the deforestation problem. For example, the European Union (EU), which also wish 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 forest stewardship certification programs.

2.2. Synergy effects of international policy instruments

The 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 distinguised: (i) trade instruments sanctionning illegal logging; (ii) forest stewardship certification, with the expectation that certified products can meet a greater international demand and reach a higher price than non-certified products; (iii) debt-for-nature swaps where deforesting countries accepting to extend their protected areas obtain debt relief; (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, impact 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 money received trickles down to them – or the investment capacity of the state. They may contribute greater foreign exchange earnings and to debt alleviation. However, the effects of these macroeconomic changes on deforestation are less foreseeable. They can either reinforce the initial effort towards deforestation reduction, or mitigate it.

For instance, the macroeconomic optimization model of Kahn and McDonald (1995) reveals that in order to payback debt, developing countries tend to adopt short term policies which work against conservation. They illustrate the fact that debt-for-nature swaps have double positive synergy effects on deforestation, because they impose the creation of conservation areas by agreement, and relieve the pressure of debt. In a similar way, we argue that the net effect on forest area of incentive transfers can either be positive or negative, depending on the way they indirectly affect drivers of deforestation. For example, large REDD transfers can effectively relieve pressure on forest resources if allocated to poverty alleviation programs in rural forested area (Karsenty, 2008). However, if these funds can be used to promote activities competing with forest cover, such as infrastructure development (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, anilihating the short term efforts to avoid deforestation, provided by countries in order to be eligible.

International policies	Direct expected impact	Indirect economic impact	Effet 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 area Compensation of opportunity costs of avoided deforestation	Greater foreign exchange earnings Debt alleviation Greater investment capacity by rural communities Greater state investment capacity	Positive? Or negative?

Table 1: Direct and indirect impact of international instruments

In face of all international policy instruments tabled in current international negotiations, there is a need to assess better what their direct and indirect impacts are on deforestation drivers. Most economics models of deforestation try to identify these drivers of deforestation to explain the growing pressure on forest cover (Kaimowitz and Angelsen, 1998). However, few econometric studies attempt to link their conclusions with interrnational policies.

2.3. Deforestation patterns and relative forest endowment

Another issue at stake in current multilateral negotiations on forest is the double necessity to (i) better tailor international policy instruments to the diversity of so-called “national circumstances”. Indeed, not all tropical countries display 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. (ii) However, although domestic policy options to reduce deforestation can vary, there is a need to design the most inclusive international scheme as it is the best insurance against leakage.

Our objective therefore is not to identify the best policy option for each country but rather to analyse whether it would be relevant to design better-adjusted international instrument packages for different types of deforesting countries. This is why we conduct a country-level panel data analysis linking the rate of forest area (capturing the deforestation phenomenon) to variables measuring the direct and indirect effects of international instruments.

Most econometric analysis of deforestation conduct pooled estimations (Combes Motel et al., 2009; Allen and Barnes, 1997; Shandra and al, 2008; Bhattarai and Hammig, 2004) or clustered 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 continent "*provides a comparable set of environmental and economic conditions across a wide geographic area*". However, climate or geographic locations and characteristics can be captured through a fixed-effect model; while it would be inaccurate to argue that the response of countries to the deforestation drivers will be the same among countries just because of their belonging to the same continent. Moreover, this segmentation by continents does not allow to take into account the "forest transition" phenomenon, which is essential in the understanding of the deforestation dynamics. Forest transition theory argues that it is unlikely that massive deforestation is 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. Brazil, Cameroon or Indonesia, in contrast continue to deforest because of the abundance of their forests. We therefore chose to estimate three models for three average levels of forest endowments: we stick to the clustering chosen by FAO: the low forest endowment[6] countries with 10 to 30% of forest cover (LE group), the medium endowment countries with 30 to 50% of forest cover (ME) and the high forest endowment countries with more than 50% of forest cover (HE). This last group corresponds to the pooling of two categories of FAO, in order to have equivalent quantity of countries by country groups.

[6] Forest endowment is total forest area over total country's area in percentage

3. Data and model specifications

3.1. Econometric Model

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

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

Table 2 - List of 56 countries included in the model, by continent and by endowment group

The contribution of our paper is to mobilize a recent data base over a fifteen year period, from 1995 to 2005: it is one of the first econometric analysis capturing the deforestation dynamics during the 2000s. Moreover, all developing countries with more than 10% of forest cover are included, except for 4 countries with an incomplete data set[7]. Equatorial Guinea was also excluded from the sample because its income per capita is 3 times the average. We therefore have a sample of 56 countries in our panel-data (table 2), subdivided into three sub-samples according to their initial forest endowment relative to their total area. There are 16 countries in LE group, 18 countries in ME group and 22 in HE group.

The best data on natural forest cover[8] are collected by the World Resources Institute: but they are available for only 3 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 which has been cleared but that will be reforested in a close future. Only forest plots whose surface exceed 0.5 hectare and whose canopy covers at least 10% of the surface area are included. We use this forest cover data taken from 2005 FAO Forest Resources Assessments (FRA). This new data base is much more reliable than the previous FAO data base (FAO FRA of 1980 and 1990, used by the majority of previous studies) which were based on old inventories and extrapolated from a single data point with deforestation model depending only 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 through satellite use, "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 use a variable called "forest area" as our dependent variable. It corresponds to the forest area as it is given in the 2005 FAO FRA relative to the total area. Descriptive statistics of regression variables are presented in appendix 1. The higher deforestation rate is observed in the ME country group. It is worth noticing that the LE group has a positive reforestation rate during the study period. This is due to the replantation strategy of countries like China, India, Chile, Swaziland and Vietnam. However, when China is left out of the sample, the average forest area in the LE group declines. In the ME group, the Ivory Coast has also reforested steadily over the 15 years of the study period and Costa Rica since 2001; in the HE group, Guyana and Belize have a rate of deforestation close to 0.

[7] Botswana (LE country), Liberia (ME country), Myanmar (HE country) and Suriname (HE country)

[8] this is the natural forest cover observed by the Landsat satellite, later verified using GIS and field observation data and compiled by the Global Environmental Monitoring Systems (GEMS) and FAO.

We use a log-log specification for our model; this transformation allows an interpretation of the coefficients in terms of elasticity. The model reads as follows :

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

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

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

We distinguish two types of explanatory variables: a first set of variables captures the effects of deforestation drivers, mainly forest exploitation and agricultural production; the second set of variables is included to measure the indirect impact of international policy instruments.

Explanatory variables	Entitled	Unit	Dataset	Expected sign
Rural population	POPRUR	Rural population/total population	FAO	Negative
Export value of forest products	XFOR	Current millions $US	FAO	Negative
Export value of agricultural products	XVAL	Current billions $US	FAO	Negative
Agricultural added value	AGVAL	Current 1 000$US per square kilometers	WB	Negative or positive
GDP per capita	GDPC	Current 1 000$US	WB	Negative
GDP per capita squared	GDPCS			Positive
External debt, total	DEBT	Current million $US	WB	Negative
Terrestrial areas protected	PA	Terrestrial areas protected/ total area by country	United Nations	Positive

Table 3 Definition and description of explanatory variables

3.2. Explanatory variables

3.2.1. Deforestation drivers

Population pressure and poverty are considered as 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 looks consequently for new area of expansion to respond to the increasing needs in food and fuelwood. Shandra et al. (2008) point out the role of growing populations of peasants and shifting cultivators in the sharp increase of deforestation process. In Bhattarai and Hammig (2001) and Shandra et al. (2008), population growth rate and rural density are introduced in a deforestation model. Their results show that rural population pressure - and not the overall population growth - is a significant factor contributing to deforestation. Tis is confirmed by Barbier and Burgess (1997), Combes Motel et al. (2009), Shandra et al. (2008), and Cropper and Griffiths (1994) only for Africa. Thus, we include rural population as an explanatory variable in our model.

Forest cover is threatened by agricultural expansion, wood extraction (fuelwood, commercial, charcoal) and infrastructure extension (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) find that improvements in agricultural productivity reduce the pressure to convert forestland to agricultural uses. Combes Motel et al. (2009) show that the higher the price of agricultural commodities, the higher the deforestation rate. When prices decrease subsequently, the deforestation rate remains high. The links between agricultural productivity and deforestation are not easily disentangled. Angelsen and Kaimowitz (2001) devote an entire book seeking to measure how technological change in agriculture may affect tropical forest cover. There are two broad responses: on the one hand, a ‘win-win’ situation where, at the macro-scale, the increase of agricultural yields leads to “economic development and growth, which, in turn, is associated to other changes that limit deforestation” and, at the micro-scale, technological change allows to intensify rather than expanding arable land. On the other hand, 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 introduce two variables in our model: the added value per square kilometers generated by the agricultural sector; and the export value of agricultural commodities. This second variable allows 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 for Latin America). We use 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] and 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 we can also explain export values by deforestation. To avoid this endogeneity issue, we lag these two variables in our model.

3.3. *Explanatory variables with likely feedback effects on deforestation process*

3.3.1. National income

One of the main findings of most studies is the correlation between economic growth and rate of deforestation, confirming for deforestation, 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) obtain a hump-shaped relationship between GDP *per capita* and rate of deforestation in Africa and in Latin America, while Koop and Tole (1999) observe an EKC for deforestation only in Asia and in Africa. The only two studies where pooled sample is used (Combes Motel et al., 2009; Bhattarai and Hammig, 2004), confirm the existence of an EKC relationship.

The general explanations are the following: low-income countries clear forests to increase arable area and fuelwood. Greater levels of income are often associated with greater rural density, which in turn accelerates the deforestation pace. However, beyond a given level of income (the so-called “turning point”), deforestation starts declining: higher income allows 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 change: “fuelwood energy predominates during early stages of development but coal and petroleum-based fuels become more important during later stages,

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

[10] The FAO (2005) evaluates 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 exports value of forestry products.

thereby reducing further forest conversion pressure" (Bhattarai and Hammig, 2004). Finally, 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 which should have a positive coefficient in the regression model.

3.3.2. Debt

We introduce 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 payback their international debt. We expect 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 confirm the importance of debt management in the tropical deforestation process.

3.3.3 Protected areas

To the previous macroeconomic variables, we have added a variable measuring the total terrestrial protected area. They 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 use 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 could intuitively expect a positive correlation between forest area and protected area, we want 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

Estimation results are reported in table 4 for the whole sample (pooled results) and for the three groups: LE, ME and HE. For the 4 regressions, the within R^2 lies between 0.24 and 0.62,

[11] equivalent to 4% of the world total area
[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

traducing a reasonably good explanatory power of our model. The split-up of the pooled sample into three country groups according to forest endowment improves the significance of explanatory variables[14].

Results of table 4 allow us to evaluate the possible complementary or substitution effects of international policy instruments to reduce deforestation. We observe that indirect unforeseen effects vary across country groups. The analysis helps us to formulate recommendations for differentiated policies designed to address the specificities of each country group.

	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

Table 4 – Estimation results

Almost all estimated parameters are statistically significant in LE and ME country groups, whereas a less clear picture is drawn for the HE country group, where few variables are significant. We tested various model specifications and several other explanatory variables but, whatever the model used, we could not identify a better model. It seems that the deforestation trend 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 which is largely supported by the exploitation of forest resources or the conversion of forests into farmland, without enough economic alternatives to

[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

be able to switch to a different development pattern. Consequently, they 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 models' 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 country group while it is –0.075 country in ME group, demonstrating that of international debt alleviation can be a truly effective international policy to curb global deforestation.

4.1. Results and policy recommendations for the low endowment country group

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

LE group's deforestation rate seems to be mainly driven by rural population pressure (which increases demand for fuelwood) and gains in agricultural productivity: competition between forest and agricultural land concerns more staple crops 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 explanation is that LE countries' protection priority is forest since they are already scarce. For instance, out of the 78 protected areas of Burkina Faso, 63 are dedicated to forests[15]. The second reason is that it is easier to create alternative activities for people who are barred from exploiting protected forest areas, and the issue of leakage is therefore less crucial than in other country groups. Domestic or

[15] http://bch-cbd.naturalsciences.be/burkina/bf-eng/index.htm

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 are expected to be very effective, be they implemented at the national level or at the project level.

4.2. *Results and policy recommendations for the medium endowment country group*

The ME country group is the only group where we confirm the environmental Kuznets curve for deforestation, with highly significant estimated parameters both for GDPC and GDPCS. It 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 confirms –partially at least - 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 test on slopes at the beginning and the ending of the interval must confirm the U-shape (Couttenier, 2008). We run the U-shape test proposed by Lind and Melhum, (2007) based on a Sasabuchi test (Couttenier, 2008). Results are given table 5.

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]

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

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 reaches it soon. 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: payments will be done only on the basis of certified avoided deforestation. To avoid the issue on 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.

[16] It is the GDP per capita of South Africa in 2008

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

In this group, as in the HE country group, we find a surprising negative elasticity between forest cover rate and protected area (- 0.29). This result can be explained by the phenomenon of internal leakage: the creation of new forest conservation area leads to intensified extraction in neighbouring areas, mainly because forest users are driven out of their traditional activity area without sufficient monetary compensations or economic alternatives. Their only option is to start deforesting in unprotected area, often at a greater rate to generate more revenue and to be able to re-invest. The establishment of forest conversation area 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 or in countries with a small share of forests. Although this is often described in qualitative analysis of deforestation dynamics, it is the first econometric analysis confirming this intuition with a full panel of tropical countries. Of course, these results should be interpreted cautiously since they only capture average trends and are using an imperfect database.

Thus, our analysis provides a better understanding of the drivers of deforestation at the macroeconomic level, and helps to draw policy recommendations for the design of international policy instruments.

We illustrate that beyond the outcomes resulting of the conditionality of policy instruments (direct impact), there are feedback effects on deforestation through changes in deforestation drivers. Some international policy instruments are better fitted to given groups of countries, whereas others should be avoided in some countries. Debt relief policy is effective in all groups. In the low endowment country 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 should be en efficient package. It differs from what should be recommended for the medium endowment country group: the REDD mechanism should privilege output-based payments, and should avoid project-level implementation to contain leakage; and forest stewardship certification should be encouraged and subsidized. International policy instruments are expected to be less effective –at least in the short term – for the high endowment country group. It pleads in favour of longer term solutions involving long-term conditional financing commitments between the international community and these deforesting countries.

Ideally, policy interventions to curb deforestation should be tailored to local specificities but there is a risk that favoring small-scale projects does 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 can contribute to improve the fit between international policies and the needs of country groups 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 area*100)*	**S.D.**	**18.19**	**6.90**	**8.15**	**10.85**
	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 area*100)*	**S.D.**	**12.29**	**8.012**	**8.68**	**15.43**
	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$US)	**S.D.**	**1.559**	**1.799**	**1.327**	**1.506**
	Min	0.0849	0.0978	0.119	0.0849
	Max	8.281	8.281	7.447	6.714
GDPCS	**Mean**	**4.227**	**4.543**	**3.124**	**4.900**
	S.D.	**9.330**	**12.651**	**7.396**	**7.710**
	Min	0.00721	0.00956	0.0141	0.00721
	Max	68.569	68.570	55.456	45.078
POPRUR	**Mean**	**.0412**	**0.0619**	**0.0562762**	**0.0137**
(Rural population/ total	**S.D.**	**0.0517**	**0.0628**	**0.0558**	**0.0126**
population)	Min	**0.000792**	**0.00120**	0.00305	0.000792
	Max	**0.247**	**0.246**	0.247	0.0619
VAAG	**Mean**	**32.267**	**25.230**	**40.967**	**30.268**
(Current 1 000$US per square	**S.D.**	**35.6103**	**25.908**	**38.635**	**37.723**
kilometers)	Min	0.470	1.440	0.470	1.538
	Max	196.92	116.091	172.765	196.922
XAG	**Mean**	**1766.035**	**2 315.78**	**1 721.022**	**1 403.05**
(Current billions $US)	**S.D.**	**3530.229**	**4 188.948**	**2 506.939**	**3 679.21**
	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 $US)	**S.D.**	**990.3407**	**964.964**	**1 090.171**	**923.336**
	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 $US)	**S.D.**	**44 333.47**	**48 861.97**	**43 744.04**	**40 509.8**
	Min	142.733	259.561	698.507	142.733
	Max	281 612.1	281 612.1	171 161.7	244 107.7