# Deforestation and credit cycles in Latin American countries♠

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Abstract

Latin American countries have exhibited rapid deforestation rates as well as macroeconomic instability that were often rooted in credit booms and crunches episodes. Theoretical pieces of explanation are provided establishing a causal link between credit cycles and deforestation driven by agricultural land increases. Deforestation occurs in response to interest rates movements primarily because of the irreversible character of forest conversion in a two-sector model: modern vs subsistence sector. Econometric tests are conducted on the 1948-2005 period and a sample of Latin American countries. The deforestation database is a compilation of FAO censuses and several measures of credit cycles are calculated as well. Usual control variables are introduced in deforestation equations which are run with different measures of credit cycles and different estimators. The results show a significant deforestation impact of credit crunches, thus corroborating the influence of macroeconomic policies in natural resources and environmental issues.

Keywords : Credit cycles, Deforestation, Latin America, Macroeconomic policies

JEL classification: Q23, O13, O11

## 1. Introduction

Latin American countries experience a rapid deforestation: annual average deforestation rates in the most recent periods are twice the world's ones: 0.46% versus 0.22% over the 1990-2000 period and 0.51% versus 0.18% over the 2000-2005 period.[1] Since primary forests in these countries account for 56% of the world's primary forests, the Latin American paces of deforestation raise particular concern and have emerged as an international issue related to global warming and biodiversity losses.[2] Forest preservation sustains the objectives of the United Nations Framework Convention on Climate Change Convention and delegates who met in Bali in late 2007 agreed to consider standing forests as a device against global warming. Latin American countries have also expressed their interest in participating in a Forest Carbon Partnership Facility. Moreover, forest preservation in Latin American countries meets also the objectives of the Convention on Biological Diversity in as much as at least 10 Latin American countries have more than 1,000 native tree species [31] and a great amount of species extinction occurs in tropical environments [46].

National initiatives remain however important but rely on the understanding of the deforestation process which has been extensively studied. According to Geist and Lambin [36], "source" or "proximate" causes of deforestation relate mainly to economic activities taking place at the local level such as investments in infrastructure and road networks [4, 20], expansion of cattle ranching and agricultural activities [11] and finally commercial logging

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[1] These figures are not strictly comparable to the figures calculated in the paper since FAO's deforestation rates are calculated by summing annual variations of forest areas. Moreover Mexico is not included in the figures reported by the FAO [31, 32].

[2] Climate change from forest conversion may also occur locally [56] and preserving biodiversity also yields domestic benefits [21].

[57]. Geo-ecological factors such as soil quality, rainfall and temperature conditions are considered as “predisposing” factors of deforestation which condition the links between “proximate” and “underlying” causes. The latter operate mainly at the macro level and are related to social processes and economic policies such as the population pressure [13, 22], landownership and income distributions, national and regional development strategies [42], agricultural research and technological change as well [52]. The poor quality of institutions tends to accompany deforestation. Weakness of property rights creates incentives to capture rents generated by forest extraction [27]. Inappropriate rules of law may incite forest dwellers to become agents of deforestation [51]. Moreover, bribes and agricultural lobbies generate rural subsidies that both encourage low agricultural productivity and deforestation [16].

Other studies have highlighted the role played by macroeconomic - fiscal, exchange rate and / or sectoral - policies in the deforestation process, *e.g.* [2]. Exchange rate depreciation promotes exporting sectors and by the way forest conversion. Exchange rate variations may however have an ambiguous impact on deforestation, depending on their permanent or transitory patterns [5]. The terms of trade affect deforestation of timber exporting countries. An improvement in the terms of trade may be the result of an increasing demand for timber products. If a country relies on its export earnings, an increase in the terms of trade will reduce the long term forest stock [9]. Openness may however dampen the effect of population pressure on forests when giving new opportunities for the economy [39]. Debt is also an important issue for deforestation in developing countries. Debt can induce myopic behaviours and foster forest depletion especially when a country must meet its international financial commitments [24]. Although debt for nature swaps may impede such a process [41], the evidence for Latin American countries is not clear cut. Gullison and Losos [38] assert that agricultural and timber exports did not increase with growing external debt. It is hard to isolate the peculiar role played by the external debt among other macroeconomic factors in land degradation in the 80's. Moreover, debt repayments may have been responsible for drastic public spending reductions in infrastructures provision that have a positive effect on deforestation.

This paper provides further investigations into underlying causes related to a peculiar macroeconomic feature of Latin American countries. For many years, the latter are subject to credit cycles defined as successive expansion and slowdown phases in the supply of credit and thus in strong variations in the opportunity cost of capital. For instance, Latin American countries experienced credit stagnation in the late 90s, *e.g.* [6], which coincides with an increase in deforestation rates. Credit expansion has ambiguous effect on deforestation.. On the one side, credit allows to finance investments in infrastructures that boost deforestation [47, 33, 23]. On the other side credit facilitates the adoption of more capital intensive agriculture which is less forest consuming [4, 19]. This paper rather concentrates on the consequences of credit cycles. Credit cycles are deemed to modify relative prices, and thus are expected to influence resources allocation between sectors in accordance with their capital intensities. It is argued that both credit expansions and credit crunches may have positive effects on deforestation *i.e.* credit cycles foster deforestation. This proposition is formalized with a two sectors model which posits a modern agricultural sector and a subsistence one. This dual economy model is hypothesised to catch the basic features of Latin American economies which exhibit a deforestation path in the long run. Economic agents clear forested areas in order to increase their land plots. Interest rates movements pour financial instability into agricultural decisions. It is shown that deforestation occurs in response to interest rates increases and decreases as well primarily because of the irreversible character of primary forest conversion.

The remainder of the paper is organized as follows. Section 2 puts forwards stylised facts relating deforestation and credit cycles in Latin America. Section 3 offers a theoretical framework of the engines of deforestation. Section 4 provides some econometric results and Section 5 concludes.

## *2. Deforestation and credit cycles in Latin American countries*

### 2. 1. Why focusing on credit cycles effects?

Latin American countries have experienced pronounced credit cycles characterised by phases of strong acceleration of credit growth (credit or lending booms) followed by a drastic reduction in credits (credit crunches) from world war II onwards, e.g. [17, 37]. The first three decades (50s to 70s) are marked by a rapid credit expansion, with several deceleration episodes (see Figure 1 in the statistical appendix). Tight credit policies in the 80s are combined with financial repression in the aftermath of the debt crisis. The financial liberalisation in the late 80s spurred a credit expansion in the early 90s followed by a credit stagnation episode since the late 90s [6]. More generally, credit cycles either occur with economic policies reversals (*e.g.* the brazilian experience of tight credit against inflation in the 60s [49]; or the adoption of the Basel Accord in the 90s [7]; or fluctuations in international liquidity availability as well (*e.g.* petrodollars in the 70s [1]). Braun and Hausmann [15] show that the frequency of credit crunches is higher in Latin America than in other developing countries; these credit crunches are deeper in magnitude and relatively long-lived. They also argue that the recent episodes of credit crunches have been more frequent and severe than before. Credit cycles are thus a prominent feature of Latin American countries for many years and are a key ingredient of their macroeconomic instabilities.

Why Latin American countries are particularly prone to these credit crunch and credit boom periods? Three pieces of explanation can be put forward: (i) a poor financial development (weak banking supervision, limited access to collateral) leads to strong moral hazard problems and makes Latin American economies more prone to credit instability [17], even after the implementation of financial liberalization [17, 43]; (ii) the structure of balance sheets of Latin American firms raises their vulnerability to exchange rate shocks through the currency mismatch mechanism and this vulnerability is transferred to the banking system; (iii) the Latin American countries have hardly implemented countercyclical monetary policies, either due to the "original sin" effect in floating exchange rates [30] or due to politicians preferences in fixed exchange rate regimes.

Admittedly, credit cycles are associated with business cycles but one may easily think about sectoral effects as well. It is argued here that credit cycles are of peculiar importance for environmental issues for different reasons. First, credit cycles are considered to be symptoms of financial constraints, *e.g.* [17], *i.e.* to be closely linked with credit rationing which is still perceived by rural households despite 'market friendly' reforms in the agricultural sector [14]. In such a situation, credits are allocated mainly to large landowners who can justify substantial collaterals *i.e.* lands, consume relatively more land and are more readily able to clear the forest [53]. Second, credit cycles spur on asset prices and thus land prices variations which may affect deforestation. Third, credit cycles may be the pretext to public interventions aimed at providing peculiar public goods like forested lands or subsidized credits to the agricultural sector.

### 2. 2. Patterns of deforestation in Latin America

Data frequency on forests allows calculating only period averages from 1948 to 1961. Although annual data are available since the 60s, period averages are still calculated since annual data are often interpolations.[3] 20 countries are included in the sample within each

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[3] Annual deforestation rates between 1948 and 2005 are reported in Table 2 in the statistical appendix. Data sources from FAO Censuses [31, 32] are reported in Table 3 in the statistical appendix

period.[4] Among the 20 Latin American countries included in the sample, there are 4 Caribbean, 7 Central American and 9 South American countries.

Deforestation rates in Latin American countries differ sharply across space.[5] Deforestation rates are high during the 50s, the 60s and the 70s, then drop in the 80s and increase sharply since the second half of the 90s. High rates of deforestation in the 50s and 60s did not raise particular concern in this post-war period which was characterised by the overwhelming goal of economic growth and great optimism [29]. Large parts of primary forests disappeared with for instance the destruction of the Atlantic rainforest in Brazil due to coffee plantations expansions [55]. Import substitution strategies (ISS) have been conducted in the 50s and the 60s in many Latin American countries. Although they gave a non negligible importance to mining and forest products industries [49], it is considered that they reduced natural resource use by promoting industrial sectors. Nevertheless, despite the ISS' anti-agricultural bias, it is alleged that ISS gave less incentives to conserve natural resources. For instance, land was under-utilized in large agricultural establishments of which lands may have encroached on

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[4] The first period is an exception: forest coverage statistics are only available in 7 countries. Among 24 potential Latin American countries, 3 countries are dropped (Chile, Surinam and Uruguay) since they exhibit a forestation profile throughout the period. Argentina is also dropped since deforestation has taken place only on the last 2 periods.

[5] A simple and preliminary decomposition of the deforestation process shows that idiosyncratic factors are at work. This can be shown by estimating a regression equation of average annual deforestation rates on periods and country fixed effects. The magnitude of idiosyncratic factors may be inferred from the calculation of $1-R^2$ of the regression. The latter is 0.82 which must be interpreted as an upper bound on the variance of independent idiosyncratic factors since the total variability may also be the result of measurement errors.

forested areas and the management of environmental base in agriculture was more depletive [53].

If deforestation figures among countries are compared, highest deforestation rates are found in Central American countries: five Central American countries are among the seven that exhibit an average deforestation rate greater than 1% over the whole period[6] Costa Rica experienced for instance the highest rates from the fifties to the beginning of the eighties, illustrating the predominant views of economic development in Latin America: agri-business exportation sector, import substitution strategy until the structural adjustment programs which stopped deforestation in the early 80s. Since then, forest preservation initiatives have reduced the pressure on forests [26]. The same story is at work in Nicaragua and Honduras which have considerably developed their beef exports. The proximity of the United States has stimulated the demand for agricultural and cattle products. The Latin American Agri-business Development (LAAD) Corporation is deemed to have contributed to the process when pouring large amounts of capital into Central American countries in the 60s.

### 2. 3. Is there really a link between deforestation and credit cycles episodes?

At first glance, there is no obvious correlation between the highest country average deforestation rates and the most pronounced credit cycles episodes. Among the seven countries having high deforestation rates, only one (Nicaragua) is also characterised by a strong credit instability as measured by standard errors of credit growth rates.[7] Second, the coincidence between periods of high deforestation and credit cycles is not clear-cut: it seems

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[6] These countries are El Salvador, Costa-Rica, Honduras, Nicaragua, and Panama; the remaining countries being Jamaica and Paraguay.

[7] Table 4 in the statistical appendix.

that credit booms are associated with an acceleration of deforestation, but this correlation is contradicted in the last period that is characterised by a tightening of credit and an increase in deforestation. This result is not surprising since many idiosyncratic factors affected credit cycles during the last decades. Among these factors it can be mentioned that financial reforms were implemented at different times [29],[8] but political factors played of course a prominent role.[9] Country-period statistics do not put more light on a deforestation-credit cycles relationship: there is only 22% of coincidence between the highest deforestation figures and the highest credit growth rate instabilities.

Moreover, any simple correlation between deforestation speeds and credit growth rate instabilities must be cautiously interpreted. Indeed (i) simple correlations do not allow drawing causal links between deforestation and credit cycles, (ii) measuring credit cycles implies defining a long term or potential credit, and (iii) it is hard to disentangle the effects of the different stages within credit cycles (*i.e.* credit booms and credit crunches). These difficulties elicit three constraints to test relevantly the existence of a causal relationship between deforestation and credit cycles: (i) the need to use multivariate regressions (ii) the need to define credit cycles as the gap between its current value and a trend, and (iii) the need to distinguish the impact of credit booms from credit crunches' ones.

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[8] Chile and Mexico were among the first reformers in the mid-80's while Dominican Republic and Ecuador liberalised only in the mid-90's.

[9] For instance, the military government implemented a sharp tightening of credit when it seized the power in 1964 in Brazil

## 3. Deforestation Modelling

Let us consider an agricultural economy made of two sectors.[10] The first one is a "subsistence" sector and the second one is a "modern" sector. The subsistence sector has a production function $G$ which uses land $H^G$ and labour $L^G$ only. The subsistence sector barely access credit markets, which impedes capital accumulation. Despite all these constraints, economic agents are deemed to maximise their profits according to the "poor but efficient" hypothesis [50]. It is hypothesised that the subsistence sector is representative of shifting or "slash and burn" agriculture. It consists in periodic clearing of forested areas for short periods of cultivation interrupted by long fallow periods which are essential for fertility restoration, weeds control and forest regeneration (secondary or degraded forest) purposes. Population pressure reduces fallow periods and generates deep advances in forested areas [44]. The production function $F$ in the modern sector, depends on three production factors: land $H^F$, labour $L^F$ that equals $L$-$L^G$, and capital $K$. The modern sector pictures agricultural and or livestock-keeping activities that may have an access to formal and or international agricultural markets. The modern sector output is sold at price $p$; the *numéraire* is the output price of the subsistence sector. Land property rights insecurity restrains agents from considering forest as a natural asset which generates inter-temporal income flows: agents are prompted to favour immediate returns. Their behaviour is thus modelled using instantaneous profit maximisation.

Both production functions have positive and decreasing marginal productivities, and non increasing returns to scale. They satisfy Inada conditions and allow factors substitutions. In addition, cross second derivatives are non negative. Labour moves freely from one sector to

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[10] Many researchers emphasised the dual character of Latin American agriculture, *e.g.* [28, 40]

another one with a constant total supply $L$. Both sectors share a common wage $w$ that induces labour allocation in the economy. Capital use is determined by its opportunity cost $r$ which includes a rental rate and an agency cost. Land is a specific factor of which prices are $h^G$ and $h^F$ in the subsistence and modern sectors respectively. It is assumed that land markets are poorly developed. Hence $h^G$ and $h^F$ represents clearing marginal costs, opportunity costs generated by forest depletion and conflict costs within local populations. Land specificity derives from differences in localizations, soil qualities, and legal statutes. For instance, people concerned by subsistence (or traditional) agriculture, are located in the forest whereas modern agricultural activities rather take place in pioneer fronts.

Tropical deforestation is mainly an irreversible process which is the result of agricultural land encroachments [31] from the subsistence and modern sectors. Increases in $H^F$ or $H^G$ are defined as deforestation, e.g. [8], whereas decreases in $H^F$ or $H^G$ are increases of fallow lands or degraded forests. Nevertheless, it is possible that a small portion of fallow lands turn over to forest in the subsistence sector. Indeed, secondary forestation is usual in areas where forests have been degraded by slash-and-burn agriculture. Forest re-growing is more difficult in the modern sector where forest clearing is deemed to be more complete. Fallow lands provide several products and services and allow raising cattle which increases the value of land [35]. It may be thus profitable even in the modern sector, not to reduce them under increasing demand for agricultural land.

Two models are presented. The first one allows land input adjustments in the modern sector. This hypothesis is relaxed in the second one. Land fixity in the modern sector can be justified in three ways. Modern agriculture is not land extensive: agricultural output increases can be the result of capital and / or labour increases. Legal constraints may also prevent land extensions in this formal sector. Moreover, land encroachments in tropical rainforest may be prohibitive: lack of infrastructures, clearing costs, costly land improvements in cleared areas.

In the second model, the subsistence sector is the only cause of deforestation. For instance, in Central America capital intensive agricultural establishments had few impacts on forest resources. Forest clearance was mainly the result of increased pressure generated by subsistence farmers in areas endowed with a rich biodiversity and forests [18].

### 3. 1. Two engines of deforestation: modern and subsistence sectors' expansions

In a context where land is a choice variable in both sectors, the profit maximization is made upon $H^F$, $H^G$, $L^G$ and K:

$$\max_{L^G, K, H^G, H^F} \pi \equiv G\left(L^G, H^G\right) + pF\left(L - L^G, H^F, K\right) - wL - rK - h^G H^G - h^F H^F$$

Subscripts indicate first derivatives and stars the optimum values in the first order necessary conditions:

$$\frac{\partial \pi^*}{\partial L^G} = 0 \Leftrightarrow G_L\left(L^{G*}, H^{G*}\right) - pF_L\left(L - L^{G*}, H^{F*}, K^*\right) = 0 \qquad (1)$$

$$\frac{\partial \pi^*}{\partial K} = 0 \Leftrightarrow pF_K\left(L - L^{G*}, H^{F*}, K^*\right) - r = 0 \qquad (2)$$

$$\frac{\partial \pi^*}{\partial H^G} = 0 \Leftrightarrow G_T\left(L^{G*}, H^{G*}\right) - h^G = 0 \qquad (3)$$

$$\frac{\partial \pi^*}{\partial H^F} = 0 \Leftrightarrow F_H\left(L - L^{G*}, H^{F*}, K^*\right) - h^F = 0 \qquad (4)$$

Provided the sufficient order condition holds, the optimal choice functions are implicit functions of the parameters and especially of *r*. The comparative static exercise is interpreted as the simulation of a credit crunch (boom) when *dr* is positive (negative).[11] Taking also into account the properties of production functions, the results are the following:

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[11] See in the mathematical appendix the derivation of the second order conditions and the comparative static exercise.

$sign\frac{dL^G}{dr} > 0$; $sign\frac{dH^G}{dr} > 0$; $sign\frac{dK}{dr}$ ambiguous; $sign\frac{dH^F}{dr}$ ambiguous

An increase in $r$ unambiguously increases the output in the subsistence sector. The latter is obtained by labour and land inputs increases. According to (3) $H^G$ and $L^G$ move the same way. Indeed, an increase in labour input $L^G$ induces an increase of the marginal productivity of land ($G^*_{HL} > 0$): the optimum is restored by an increase in $H^G$ ($G^*_{HH} < 0$).

The opportunity cost $r$ has an ambiguous effect on land inputs and capital in the modern sector. Additional hypotheses can be put forward to solve this ambiguous effect. Indeed if $G^*_{LL} + pF^*_{LL}$ is strongly negative then labour reallocation towards the subsistence sector induces a sharp decrease in the marginal profitability of labour. The optimum can be restored in three ways: an increase in $H^G$, a decrease in $H^F$ or a decrease in $K$. The first two ones are insufficient if cross derivatives $G^*_{LH}$ and $F^*_{LH}$ are negligible. Then, a decrease in $K$ restores the optimum (equation 1).

According to equation (4), a decrease in $K$ induces a decrease in the marginal productivity of land in the modern sector ($F^*_{HK} > 0$). This effect is magnified by a decrease in labour inputs in the modern sector ($-F^*_{HL} < 0$). The optimum will be restored by a decrease in $H^F$ ($F^*_{HH} < 0$). Since labour, capital, and land inputs decrease in the modern sector, the output is negatively affected by a credit crunch.

According to equation (2), the increase in the marginal productivity of capital induced by $r$ is obtained by a decrease in $K$ since $L^F$ and $H^F$ decrease.[12]

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[12] There theoretically exists another story which looks however paradoxical. Indeed according to (2), an increase in $r$ can induce an increase in $H^F$. According to (4), $H^F$ and $K$ move accordingly. In that situation, a credit crunch generates a counterintuitive increase in $K$.

The total effect of the credit crunch on deforestation is positive in as much as waste lands in the modern sector cannot compensate forest clearing in the subsistence sector.

A credit boom represented by a decrease in *r* induces deforestation as well. Indeed, it generates an increase in the output in the modern sector which is forest consuming. Although land inputs decrease in the subsistence sector, they cannot be compensated for.

Deforestation is generated whatever the change in *r*. This result relies heavily on the non-specificity of land inputs in both sectors. Deforestation is driven by small (subsistence) agriculture during credit crunch episodes whereas it is driven by large-scale (modern) agriculture during credit boom episodes.

### 3. 2. One engine of deforestation: subsistence sector's expansion

In a context of land fixity for the modern sector, the profit maximization is made only upon $L^G$, $K$ and $H^G$:

$$\max_{L^G, K, H^G} \pi \equiv G\left(L^G, H^G\right) + pF\left(L - L^G, \overline{H}^F, K\right) - wL - rK - h^G H^G - h^F \overline{H}^F$$

Subscripts indicate first derivatives and tildes the optimum values in the first order necessary conditions:

$$\frac{\partial \tilde{\pi}}{\partial L^G} = 0 \Leftrightarrow G_L\left(\tilde{L}^G, \tilde{H}^G\right) - pF_L\left(\tilde{L}^G, \overline{H}^F, \tilde{K}\right) = 0 \quad (5)$$

$$\frac{\partial \tilde{\pi}}{\partial H^G} = 0 \Leftrightarrow G_H\left(\tilde{L}^G, \tilde{H}^G\right) - h^G = 0 \quad (6)$$

$$\frac{\partial \tilde{\pi}}{\partial K} = 0 \Leftrightarrow pF_K\left(\tilde{L}^G, \overline{H}^F, \tilde{K}\right) - r = 0 \quad (7)$$

Provided the second order condition holds with a strict equality, the implicit function theorem applies. The profit and the optimal choice functions depend on the parameters. The same comparative static exercise is done (i.e. a credit crunch (boom) occurs when *dr* is positive (negative) of which results are not ambiguous:[13]

$$sign\frac{d\tilde{L}^G}{dr} > 0\,;\; sign\frac{d\tilde{H}^G}{dr} > 0\,;\; sign\frac{d\tilde{K}}{dr} < 0$$

An increase in *r* unambiguously increases the output in the subsistence sector. The latter is obtained by labour increases and deforestation. The output in the modern sector decreases. When *r* decreases, land use decreases i.e. waste lands increase. In this model capital increases compensate for decreases in land and / or labour inputs. Credit crunches fuel deforestation. On the contrary, credit booms do not induce deforestation. But credit cycles and more generally macroeconomic instability characterised by successive credit booms and crunches fuel deforestation.

## 4. Application to Latin American countries

### 4. 1. Data and econometric specification

The dependent variable is the rate of deforestation from FAO censuses and databases [31, 32]. It is computed over five years periods to mitigate annual and random measurement errors in deforestation data.[14] All explanatory variables are also five years averages which allow taking into account delays in adjustment processes and dampening short term influences in the deforestation process.

*Credit cycles measures*

As in other emerging countries, credit crunch may be mainly supply driven. Admittedly credit crunches can theoretically be triggered by reductions in loan demand as well. This is the case when investments returns fall sharply, and one expects that loan demand reductions

[13] The calculations are reported in the mathematical appendix

[14] Except for the first period, 1948-1958 and the last one: 1999-2005

imply declining interest rates. This scenario is however not at work in the context of developing and emerging countries. An explanation of this can be provided when considering moral hazard and adverse selection on credit markets [54]. Asymmetric information between lenders and borrowers generates credit rationing: there is structurally an excess demand for loanable funds since borrowers cannot raise their interest rates in order not to affect the riskiness of borrowers and / or project financed by borrowed funds. In that context, the equilibrium quantity of credit is determined by supply shifts. Information asymmetries and hence credit rationing are arguably stronger in developing and emerging countries than in industrialized ones. Moreover interest rates were largely managed in Latin American countries until the eighties, *e.g.* [6].

In this context, the opportunity cost of borrowing is better captured by variations of credit flows than by interest rates. The size of credit cycles is assessed in two different ways. First, a measure of credit instability is computed as the standard error of the real credit growth rate. Second, a credit gap is calculated from real total domestic credit series (*i.e.* nominal value of credit deflated by the CPI index). This credit gap is calculated yearly as the difference between actual and potential real credit, expressed in terms of potential real credit and then averaged over the period. Positive (negative) values are interpreted as credit booms (crunches). Since credit booms and credit crunches may have a different impact, a dummy variable is introduced which is set to 0 for a credit boom and 1 for a credit crunch. This dummy variable is then multiplied by the credit gap.

Potential real credit is calculated with the Hodrick Prescott filter (HP) which minimizes the deviation from a trend under a constraint that penalizes the variability of the trend. The smoothing parameter (Lagrange multiplier) is set to 100 as suggested by Hodrick and Prescott and used by Barajas and Steiner [6] to identify credit cycles in Latin America. As a robustness test, alternative credit gaps are computed using a different smoothing parameter

(150) which strengthens the linear trend.[15] Moreover, an alternative way of computing the credit gap is tested, by comparing the actual real credit growth rate to the potential annual growth rate of the GDP in Latin American countries.[16] This potential credit growth rate is assumed to be homogeneous among countries and equal to 3% or 5%.

### *Control variables*

As detailed above, deforestation is also determined by some structural factors and by others aspects of macroeconomic policies, which allows taking into account two groups of explanatory variables.

The first group includes GDP per capita and squared GDP per capita (both expressed in logarithms) according to the Environmental Kuznets Curve assumption. Numerous studies provide ambiguous results: Bhattarai and Hammig [12] or Culas [25] do not reject the hypothesis whereas Meyer, Van Kooten and Wang [45] do. Barbier's results [10] on a Latin American sample depend on the set of control variables. Initial forest area (in logarithms) and population density allow testing the impact of relative scarcity of forest resources.[17] A

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[15] Gourinchas et al. [37] use a parameter set at 1,000 but with a rolling trend which use only information available at time *t*.

[16] The use of the difference between the credit growth rate and the current GDP growth rate as a proxy of an "excess supply of credit" (instead of the potential growth rate) would not be relevant since current GDP growth is itself determined by current credit growth.

[17] Using dummy variables to catch country effects in a model which includes the lagged dependent variable can bias OLS estimates. The GMM estimator may be run on panels with a large number of countries and short time span. This is however not the case in our sample where N=20 and T=10, which implies a large number of instruments. Nevertheless, estimates

measure of economic openness (ratio trade over GDP) is also introduced. The effect of crop prices and wood prices (sawnwood) is tested as well insofar as deforestation may be driven by an increase in the agricultural and forestry profitability. These variables are taken as export unit values deflated by the American consumer price index.

The second group aims at capturing the effects of macroeconomic policy through relative price variations, *i.e.* CPI inflation rate and the bilateral real exchange rate with the United States.[18] Adopting a bilateral real exchange rate is justified by the concentration of Latin American countries international trade with the USA. Moreover, most prices of primary commodities exported by these countries are denominated in US dollars.

The estimation of deforestation determinants is made using country-specific and time-specific fixed-effects.[19] These fixed-effects mimic the influence of omitted variables that are constant over time (constant measurement errors, country characteristics, *i.e.* geographical factors such as landlockness, cultural factors, etc.) and of omitted variables common to the different countries in the sample (agricultural commodities and forest products prices, energy prices, world interest rates…). It is worth to notice that the credit gap is a generated variable,

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relying on the Anderson and Hsiao procedure [3] are given in the appendix (Table 5), of which results are not very different from OLS estimates.

[18] The real exchange rate is calculated as follows : $RER_{i,t}^{1990} = INER_{\$/i,t}^{1990}.P_{USA,t}^{1990} / P_{i,t}^{1990}$ where $INER_{\$/i,t}^{1990}$ is an index of the value of one US dollar expressed in national currency units using 1990 as a base year, and $P_{USA,t}^{1990}$ and $P_{i,t}^{1990}$ are consumer price indexes, respectively in the United States and in country (i). A rise in the real exchange rate index thus corresponds to a real depreciation.

[19] The Hausman test run on the baseline regression rejects at the 1% level the random effect model. Period and country fixed effects are respectively significant at 5% and 1% levels.

[20] thus creating an invalid inference. Nevertheless, when the generated regressor is a residual, the estimated variance of the coefficient remains correct and hence bootstrapping is not needed [48].

Insert Table 1 about there

## 4. 2. Econometric results

*Control variables*

Structural variables have similar effects regardless of macroeconomic policies variables set (Table 1). First, an Environmental Kuznets Curve is suggested: deforestation increases with the level of development when GDP per capita is smaller than 4160$, then decreases beyond this threshold. Second, the coefficient associated with the initial forest area is significantly positive thus showing a convergence phenomenon in the deforestation process.[21] Third, population density and openness variables are both insignificant. As regards density, a positive impact on deforestation may be expected in our sample since Central America countries exhibit either high deforestation and population growth figures [13]. The impact of population density may however be captured by country fixed-effects since demographic factors hardly change over time. Besides, Arcand et al. [5] found similar results and suggest that the impact of these variables could operate through relative prices. Agricultural and forest products' prices are only available from 1961 onwards, dropping about 40 observations from the sample. The variables are not significant (column 11 in Table 1) since their effects may be caught by temporal fixed effects which allow controlling for common trends in

[20] Most explanatory variables are extracted from the IMF data base. Crop and wood prices are from the FAO data base [32].

[21] According to this, half the difference between actual and steady states values of forested areas is squeezed within 17 years, other variables held constant.

international crop and forest products' prices. Whether these structural variables are kept or not does not alter the results.[22]

As regards the impact of macroeconomic policies, inflation, and the real exchange rate are both insignificant (column 1, 2 and 3 in Table 1). This result persists when macroeconomic policy variables are tested separately to reveal multicolinearity problems (columns 4 and 5). These variables are therefore dropped from the subsequent regressions (column 6 and following).

### *Credit cycles variables*

The credit instability measured by the standard error of its growth rate, positively affects deforestation rates (column 1) when controlling by the real credit growth rate. It is thus useful to consider the asymmetric effects of credit booms and credit crunches periods.

The coefficient associated with the credit gap is positive but weakly significant (column 2). When it is however multiplied with a dummy variable corresponding to a credit crunch, the estimated coefficient is negative and strongly significant. The marginal impact of negative credit gaps is given by the sum of the coefficients, and is negative (around – 0.005). When introducing a dummy corresponding to positive gap instead of a negative one, it is checked that this marginal impact is significant (column 8). This corroborates the theoretical prediction of the second model, *i.e.* credit crunches accelerate deforestation while credit booms do not. In others words, deforestation is driven by credit crunches episodes, but credit booms do not protect forests. This result is robust to the introduction of the real credit growth

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[22] Institutional quality is also taken into account since the Economic Freedom index from the Fraser Institute [34] may be considered as a potential control variable. The time coverage only begins in 1970 and thus drops 3 of the 10 periods of our sample. The non significant character of this variable (results available from the authors) must be cautiously interpreted.

rate (columns 2 and 6). The occurrence of a 14% credit crunch (1st quartile value) contributes to an additional 0.06% annual deforestation, which corresponds to 8% of total deforestation (column 7). This result enlightens that macroeconomic policies may have a significant impact on deforestation dynamics.

The asymmetric impact of credit growth is unchanged either if credit cycles are computed using a greater smoothing parameter of 150 (column 3) or if credit cycles are defined using a 3 or a 5 percent threshold corresponding to the long run potential GDP growth (column 9).[23]

Moreover, a stronger emphasis is given to the asymmetric effects of credit cycles by computing two different variables which are the sum of positive values of credit gap ("credit boom") and the absolute value of the sum of negative values of credit gap ("credit crunch") (column 11). Proceeding this way, compensation of positive and negative credit gaps, is prevented. A strong asymetric effect persists since the coefficient of credit crunch is far higher (twenty times in absolute values) as the credit boom one. The credit crunch strongly fuels deforestation while the credit boom seems to slightly decrease deforestation. One explanation of the latter effect could be the existence of some forest regeneration in the subsistence sector following a decrease in the production.

The Least Absolute Deviation (LAD) estimator (column 12) gives the median regression and hence provides results less sensitive to potential outliers. Results are qualitatively similar to the PLS estimations: credit crunches only significantly affect deforestation.[24]

## 5. Conclusion

Economists have not been tempted to link deforestation and credit cycles in Latin American countries. This can be explained by the weak simple correlation between these two

[23] The results with the 5% are available from the authors.

[24] Population density affects significantly deforestation in the LAD estimation.

phenomenons. Peculiar characteristics of Latin American countries may however motivate further investigations since many Latin American countries are land abundant, exhibit rapid deforestation rates often experience macro instability often in relation with credit boom and crunches episodes. Recent available data show a coincidence between higher financial instability and deforestation increases. This paper provides a theoretical explanation and empirical investigations of this phenomenon. Econometric tests are conducted on the 1948-2005 period on an exhaustive sample of Latin American countries. The deforestation database is derived from a compilation of censuses carried out by the FAO. Moreover, various variables measuring credit cycles are calculated. The main output of the paper is to evidence the impact of credit cycles on deforestation. Precisely, it is shown that the deeper the credit cycles, the higher the deforestation rates. The results are robust to the introduction of usual control variables.

This paper confirms the role of short-term macroeconomic policies on deforestation and thus shows that the macroeconomic instability may have broader negative effects than that is usually acknowledged. It is not only detrimental to growth and welfare, but has also a negative effect on the environment through an increase in deforestation. Therefore the effectiveness of usual instruments of environmental policies (taxation, norms and property rights) may be enhanced by macroeconomic policies aiming at downsizing credit cycles.

## *Tables*

Table 1. Determinants of deforestation. Dependent variable: deforestation rate

| Independent variables | (1) | (2) | (3) (a) | (4) | (5) |
|---|---|---|---|---|---|
| Real GDP per capita (Log) | .28 (3%) | .25 (5%) | .25 (5%) | .29 (2%) | .27 (5%) |
| Squared real GDP per capita (Log) | -.03 (3%) | -.03 (6%) | -.03 (6%) | -.03 (2%) | -.03 (5%) |
| Initial forest area (Log) | .04 (1%) | .04 (2%) | .04 (2%) | .04 (2%) | .04 (1%) |
| Population density | .07 (47%) | .11 (26%) | .10 (28%) | .10 (34%) | .10 (29%) |
| Openness (Trade/GDP) | $2.1\ 10^{-4}$ (24%) | $1.3\ 10^{-4}$ (42%) | $1.2\ 10^{-4}$ (49%) | $1.3\ 10^{-4}$ (39%) | $1.2\ 10^{-4}$ (46%) |
| CPI inflation | $-\ 7.8\ 10^{-4}$ (50%) | $6.3\ 10^{-4}$ (32%) | $7.0\ 10^{-4}$ (29%) | $6.7\ 10^{-4}$ (35%) | |
| Real exchange rate | $-4.5\ 10^{-5}$ (33%) | $-9.0\ 10^{-8}$ (99%) | $2.1\ 10^{-6}$ (94%) | | $-3.5\ 10^{-6}$ (90%) |
| Real credit growth rate | $8.0\ 10^{-3}$ (20%) | $8.9\ 10^{-3}$ (15%) | $5.7\ 10^{-3}$ (52%) | | |
| Std error of real credit growth rate | .02 (6%) | | | | |
| Avg credit gap | | $3.0\ 10^{-4}$ (10%) | $2.6\ 10^{-3}$ (49%) | $5.6\ 10^{-5}$ (9%) | $6.6\ 10^{-5}$ (5%) |
| Avg credit gap × dummy (gap < 0) | | $-7.1\ 10^{-3}$ (1%) | $-6.5\ 10^{-3}$ (5%) | $-3.9\ 10^{-3}$ (1%) | $-4.0\ 10^{-3}$ (1%) |
| R2 adjusted | 32% | 29% | 28% | 29% | 30% |
| Observations (periods, countries) | 150 (10, 19) | 147 (10, 19) | 147 (10, 19) | 151 (10, 20) | 151 (10, 19) |

Panel Least Squares estimator with robust *t* to autocorrelation and heteroskedasticity; p values in parentheses; (a) Smoothing parameter equal to 150 instead of 100

Table 1 continued

| Independent variables | (6) | (7) | (8) | (9) |
|---|---|---|---|---|
| Real GDP per capita (Log) | .28 (3%) | .29 (2%) | .29 (2%) | .32 (3%) |
| Squared real GDP per capita (Log) | - .03 (3%) | - .03 (2%) | - .03 (2%) | - .04 (3%) |
| Initial Forest area (Log) | .04 (1%) | .04 (1%) | .04 (1%) | .04 (1%) |
| Population density | .10 (34%) | .10 (35%) | .10 (35%) | .11 (28%) |
| Openness (Trade/GDP) | $9.2\ 10^{-3}$ (44%) | $1.2\ 10^{-4}$ (43%) | $1.2\ 10^{-4}$ (43%) | $1.6\ 10^{-4}$ (28%) |
| Real Credit growth rate | $9.2\ 10^{-3}$ (13%) | | | .04 (8%) |
| Avg credit gap | $3.0\ 10^{-4}$ (6%) | $6.1\ 10^{-5}$ (6%) | $-4.1\ 10^{-3}$ (1%) | |
| Avg credit gap × dummy (gap < 0) | $-\ 7.6\ 10^{-3}$ (1%) | $-4.2\ 10^{-3}$ (1%) | | |
| Avg credit gap × dummy (gap > 0) | | | $4.2\ 10^{-3}$ (1%) | |
| Real Credit growth rate × Dummy (growth rate < 3%) | | | | - .05 (6%) |
| R2 adjusted | 30% | 30% | 30% | 32% |
| Observations (periods, countries) | 151 (10, 20) | 153 (10, 20) | 153 (10, 20) | 153 (10, 20) |

Panel Least Squares estimator with robust *t* to autocorrelation and heteroskedasticity; p values in parentheses

Table 1 continued

| Independent variables | (10) | (11) | (12) |
|---|---|---|---|
| Real GDP per capita (Log) | .27 (3%) | .35 (17%) | .17 (1%) |
| Squared real GDP per capita (Log) | -.03 (3%) | -.04 (16%) | - .02 (1%) |
| Initial Forest area (Log) | .04 (1%) | .07 (1%) | .03 (1%) |
| Population density | 10 (34%) | - 10 (62%) | .09 (2%) |
| Openness (Trade/GDP) | $1.5\ 10^{-4}$ (28%) | $5.1\ 10^{-4}$ (3%) | $1.1\ 10^{-5}$ (82%) |
| Wood prices | | .02 (36%) | |
| Agricultural prices | | $-5.4\ 10^{-4}$ (74%) | |
| Real credit growth rate | $9.\ 10^{-3}$ (14%) | | |
| Avg credit gap | | $9.1\ 10^{-5}$ (5%)) | $2.9\ 10^{-5}$ (87%) |
| Avg credit gap × dummy (gap < 0) | | $-3.2\ 10^{-3}$ (9%)) | - .06 (1%) |
| Credit crunch | $6.7\ 10^{-3}$ (1%) | | |
| Credit boom | $-3.8\ 10^{-4}$ (3%) | | |
| R2 adjusted | 30% | 38% | 29% |
| Observations (periods, countries) | 151 (10, 20) | 111 (9, 19) | 153 (10, 20) |

Panel Least Squares estimator: (10) and (11) with robust *t* to autocorrelation and heteroskedasticity; Least Absolute Deviation estimator: (12) with pseudo R2 and *t* statistics calculated using residual bootstrap; p values in parentheses.

## *Statistical appendix*

Table 2. Average annual rates of deforestation in Latin American countries 48–05 (%)

| | 48-57 | 58-63 | 64-68 | 69-73 | 74-78 | 79-83 | 84-88 | 89-93 | 94-98 | 99-05 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Belize | 1.51 | 0.28 | 0.13 | 0.70 | 0.74 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.34 |
| Costa-Rica | | 3.79 | 2.52 | 2.88 | 3.37 | 4.20 | 0.61 | -0.26 | 1.01 | 0.33 | 2.05 |
| El Salvador | | 4.22 | 2.04 | 1.11 | 2.67 | 4.30 | 2.96 | 0.00 | 1.88 | 2.22 | 2.38 |
| Guatemala | 2.93 | 0.15 | 0.57 | 0.59 | 1.23 | 0.91 | -2.13 | -0.83 | 1.56 | 1.79 | 0.68 |
| Honduras | | 2.72 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.71 | 4.32 | 1.19 |
| Mexico | | -0.10 | 0.94 | 0.99 | 1.04 | 1.38 | -0.75 | -0.29 | 0.68 | 0.63 | 0.50 |
| Nicaragua | | 0.70 | 1.84 | 2.03 | 2.26 | 2.50 | 2.80 | 2.33 | 1.44 | 1.71 | 1.96 |
| Panama | | 3.11 | 0.65 | 0.67 | 0.69 | 1.71 | 2.65 | 0.79 | 0.19 | 0.13 | 1.18 |
| Dominican Rep | | 0.12 | 0.30 | 0.31 | 0.31 | 0.31 | 0.32 | 0.62 | 0.00 | 0.00 | 0.25 |
| Haiti | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.91 | 1.01 | 0.21 |
| Jamaica | | 11.26 | 0.48 | 0.49 | 0.50 | 0.51 | 0.53 | 0.21 | 0.16 | 0.16 | 1.59 |
| Tri & Tobago | 2.60 | 0.51 | 0.41 | 0.42 | 0.43 | 0.43 | 0.44 | -1.14 | 0.40 | 0.32 | 0.48 |
| Bolivia | | 0.28 | 0.42 | 0.43 | -0.19 | 0.00 | 0.00 | 0.00 | 0.59 | 0.63 | 0.24 |
| Brazil | 1.50 | 0.24 | 0.34 | 0.39 | 0.44 | -1.11 | -0.39 | 0.21 | 0.60 | 0.74 | 0.30 |
| Colombia | 0.37 | 3.39 | 0.15 | 0.68 | 0.36 | 0.00 | 0.18 | 0.56 | -0.22 | -0.03 | 0.54 |
| Ecuador | | -3.64 | 1.27 | 1.23 | 0.19 | 0.00 | 0.00 | -0.13 | 2.00 | 2.34 | 0.36 |
| Guyana | 0.01 | -0.08 | 0.00 | 0.00 | 1.55 | 0.55 | 0.00 | -0.16 | 0.11 | 0.04 | 0.20 |
| Paraguay | | -0.52 | 0.23 | 0.24 | 0.24 | 1.93 | 4.46 | 2.98 | 0.23 | 0.88 | 1.19 |
| Peru | | 1.38 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.17 | 0.19 | 0.19 |
| Venezuela | | 3.32 | 0.77 | 0.81 | 0.84 | -1.80 | -3.19 | -0.89 | 0.39 | 0.56 | 0.09 |
| Average | 1.49 | 1.56 | 0.65 | 0.70 | 0.83 | 0.79 | 0.42 | 0.20 | 0.79 | 0.90 | 0.80 |

Source: Authors' calculations from several issues of FAO censuses. See Table 3

Table 3. Forest data sources (48 -05)

| Survey (survey year) | References | Data Year |
|---|---|---|
| Forest resources of the world (1948) | Unasylva, Revue Internationale des forêts et des produits forestiers 2 (1948) | 1948 |
| World forest inventory (1958) | FAO, World forest inventory 1958 Forestry and Forest Products Division, Rome, 1960 | 1958 |
| World forest inventory (1963) | FAO, World forest inventory 1963, Rome, 1966 | 1963 |
| FAO stat (var. issues) | FAO stat. CD-rom version 1998 (available between 1989 and 1994 on the FAO website http://faostat.fao.org/) | 1968, 1973, 1978, 1983, 1988, 1993 |
| FRA – Interim report (1990) | FAO, Forest Resources Assessment 1990 - Tropical countries. FAO Forestry Paper 112, Rome, 1993 | 1998 |
| FRA – Interim report (1995) | FAO, State of the World's Forests, Rome, 1997. | 1998 |
| FRA (2005) | FAO, Global Forest Resources Assessment 2005, FAO Forestry Paper 147, Rome, 2005. | 2005 |

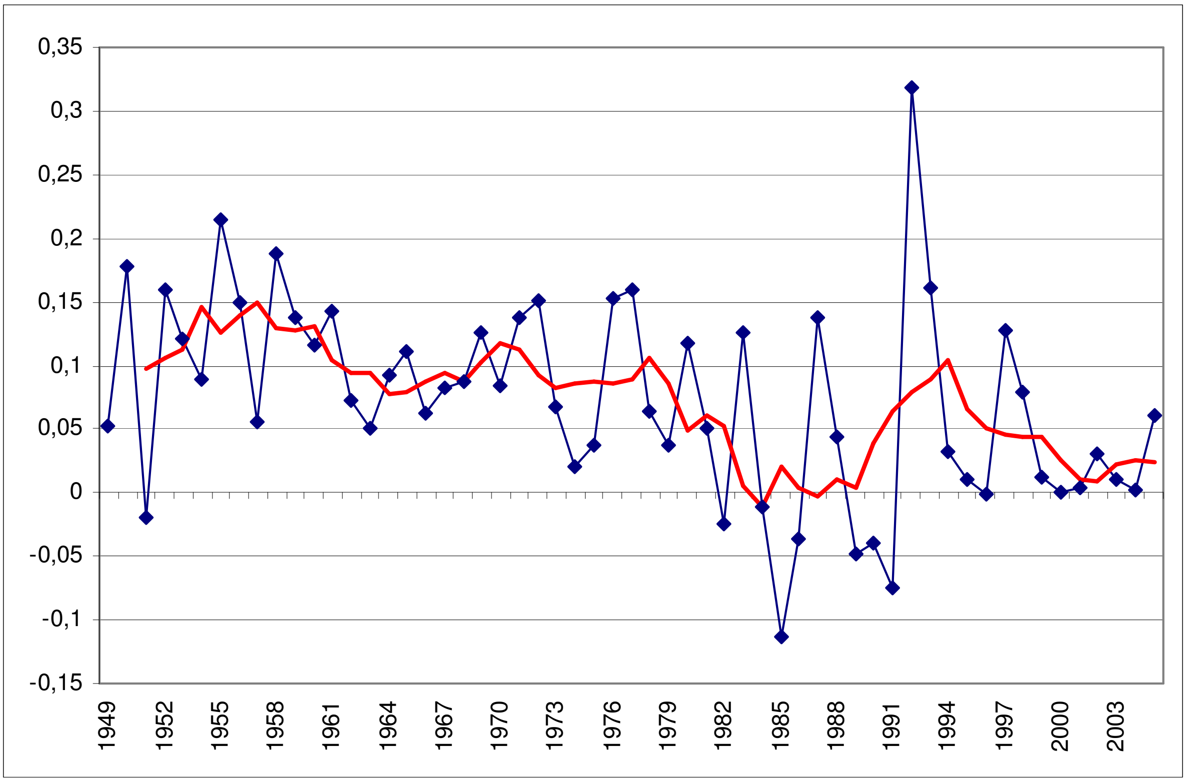
Note: In order to keep a five-year frequency until the last period, 1998 is calculated by interpolating the forest cover between 1995 (or 1990, depending on availability and consistency of data) and 2000

Table 4. Credit growth rate standard errors in Latin American countries 48 – 05

| Periods | 48-58 | 59-63 | 64-68 | 69-73 | 74-78 | 79-83 | 84-88 | 89-93 | 94-98 | 99-05 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Belize | | | | | | | 0.09 | 0.13 | 0.09 | 0.13 | 0.11 |
| Costa-Rica | 0.11 | 0.12 | 0.05 | 0.14 | 0.11 | 0.31 | 0.07 | 0.10 | 0.26 | 0.07 | 0.13 |
| El Salvador | 0.19 | 0.11 | 0.07 | 0.06 | 0.07 | 0.12 | 0.24 | 0.19 | 0.12 | 0.10 | 0.13 |
| Guatemala | 0.17 | 0.08 | 0.07 | 0.09 | 0.05 | 0.08 | 0.12 | 0.07 | 0.09 | 0.08 | 0.09 |
| Honduras | 0.25 | 0.10 | 0.11 | 0.11 | 0.05 | 0.06 | 0.05 | 0.13 | 0.10 | 0.12 | 0.11 |
| Mexico | 0.10 | 0.03 | 0.03 | 0.04 | 0.08 | 0.22 | 0.18 | 0.05 | 0.28 | 0.03 | 0.11 |
| Nicaragua | | | | | 0.08 | 0.25 | 0.51 | 1.88 | 0.11 | 0.03 | 0.48 |
| Panama | 0.12 | 0.11 | 0.07 | 0.04 | 0.10 | 0.06 | 0.10 | 0.13 | 0.07 | 0.08 | 0.09 |
| Dominican Rep | 0.26 | 0.13 | 0.08 | 0.03 | 0.12 | 0.01 | 0.16 | 0.17 | 0.09 | 0.14 | 0.12 |
| Haiti | | 0.05 | 0.09 | 0.06 | 0.02 | 0.07 | 0.13 | 0.10 | 0.05 | 0.15 | 0.08 |
| Jamaica | | 0.35 | 0.12 | 0.12 | 0.14 | 0.17 | 0.10 | 0.28 | 0.17 | 0.32 | 0.20 |
| Tri & Tobago | | 0.38 | 0.08 | 0.08 | 1.18 | 1.33 | 0.10 | 0.07 | 0.15 | 0.07 | 0.38 |
| Bolivia | 0.42 | 0.04 | 0.05 | 0.09 | 0.31 | 0.49 | 1.25 | 0.14 | 0.13 | 0.05 | 0.30 |
| Brazil | 0.06 | 0.10 | 0.17 | 0.11 | 0.13 | 0.12 | 0.40 | 0.39 | 0.34 | 0.09 | 0.19 |
| Colombia | 0.12 | 0.14 | 0.08 | 0.04 | 0.10 | 0.13 | 0.10 | 0.15 | 0.08 | 0.04 | 0.10 |
| Ecuador | 0.11 | 0.10 | 0.08 | 0.11 | 0.06 | 0.22 | 0.13 | 0.67 | 0.19 | 0.23 | 0.19 |
| Guyana | | | | | | | | | | 0.07 | 0.07 |
| Paraguay | | 0.08 | 0.09 | 0.04 | 0.10 | 0.13 | 0.06 | 0.34 | 0.06 | 0.15 | 0.12 |
| Peru | 0.06 | 0.02 | 0.09 | 0.09 | 0.08 | 0.21 | 0.24 | 0.32 | 0.27 | 0.10 | 0.15 |
| Venezuela | 0.49 | 0.16 | 0.07 | 0.06 | 0.15 | 0.07 | 0.10 | 0.21 | 0.23 | 0.22 | 0.18 |
| Average | 0.19 | 0.12 | 0.08 | 0.08 | 0.16 | 0.23 | 0.22 | 0.29 | 0.15 | 0.11 | 0.16 |

Source: Authors' calculations from IFS.

Figure 1. Real credit annual growth rates country averages




Source: Author's calculations from IFS. Note: five-year moving averages in bold

Table 5. Anderson and Hsiao estimates. Dependent variable: Opposite of end of period forest area (log)

| Independent variables | Coefficients | P values |
|---|---|---|
| Initial Forest area (Log) | -0.92 | 1% |
| Real GDP per capita (Log) | 0.12 | 29% |
| Squared real GDP per capita (Log) | - 0.01 | 21% |
| Population density | 0,15 | 26% |
| Openess (Trade/GDP) | $1.65\ 10^{-4}$ | 10% |
| Real Credit growth rate | 0.01 | 10% |
| Average credit gap | $3.69\ 10^{-4}$ | 13% |
| Average credit gap × dummy (gap < 0) | -0.01 | 9% |
| Chi-2 Sargan test | 6.41 | 96% |
| Observations (Periods, Countries) | 131 (9, 19) | |

All variables are first-differenced and the first-difference of the initial forest area is instrumented by its lagged levels. Other variables serve as their own instruments.

## *Mathematical appendix*

* The Hessian matrix evaluated at the maximum in the first model (modern and subsistence sectors' expansions) is the following:

$$D^2\pi^* \equiv \begin{pmatrix} G_{LL}^* + pF_{LL}^* & -pF_{LK}^* & G_{LH}^* & -pF_{LH}^* \\ -pF_{KL}^* & pF_{KK}^* & 0 & pF_{KH}^* \\ G_{HL}^* & 0 & G_{HH}^* & 0 \\ -pF_{HL}^* & pF_{HK}^* & 0 & pF_{HH}^* \end{pmatrix}$$

The sufficient second order condition for a maximum implies that the Hessian must be negative definite. That means in particular that $\left|D^2\pi^*\right| > 0$. The optimal choice functions are implicit functions of the parameters and especially of *r*. The comparative static exercise on *r* allows simulating credit crunch (boom) when $dr$ is positive (negative). When totally differentiating the first order conditions, the system of equations of four unknowns is the following:

$$\begin{pmatrix} G^*_{LL}+pF^*_{LL} & -pF^*_{LK} & G^*_{LH} & -pF^*_{LH} \\ -pF^*_{KL} & pF^*_{KK} & 0 & pF^*_{KH} \\ G^*_{HL} & 0 & G^*_{HH} & 0 \\ -pF^*_{HL} & pF^*_{HK} & 0 & pF^*_{HH} \end{pmatrix}\begin{pmatrix} dL^G/dr \\ dK/dr \\ dH^G/dr \\ dH^F/dr \end{pmatrix}=\begin{pmatrix} 0 \\ 1 \\ 0 \\ 0 \end{pmatrix}$$

The Cramer's rule allows deriving the optimal responses to changes $dr$ (stars omitted) taking into account the sign of the Hessian and the hypotheses on the production functions:

$sign\frac{dL^G}{dr}=-sign\left(-p^2G_{TT}F_{HH}F_{LK}+p^2G_{HH}F_{TK}F_{LH}\right)$ which is positive

$sign\frac{dH^G}{dr}=-sign\left(-p^2G_{HL}F_{HK}F_{LH}+p^2G_{HL}F_{LK}F_{HH}\right)$ which is positive

$sign\frac{dK}{dr}=sign\left((G_{LL}+pF_{LL})G_{HH}pF_{HH}-(G_{HL})^2pF_{HH}-p^2G_{HH}(F_{HL})^2\right)$ which is ambiguous

$sign\frac{dH^F}{dr}=sign\left(p(G_{HL})^2F_{HK}+p^2F_{HL}F_{LK}G_{HH}-(G_{LL}+pF_{LL})pF_{HK}G_{HH}\right)$ which is ambiguous

* The Hessian matrix evaluated at the maximum in the second model (subsistence sector's expansion) is the following:

$$D^2\tilde{\pi}=\begin{pmatrix} \tilde{G}_{LL}+p\tilde{F}_{LL} & \tilde{G}_{LH} & -p\tilde{F}_{LK} \\ \tilde{G}_{HL} & \tilde{G}_{HH} & 0 \\ -p\tilde{F}_{KL} & 0 & p\tilde{F}_{KK} \end{pmatrix}$$

The sufficient second order condition for a maximum implies that the Hessian must be negative definite. That means in particular that:

$\left|D^2\tilde{\pi}\right|<0$ and $\left(\tilde{G}_{LL}+p\tilde{F}_{LL}\right)\tilde{G}_{HH}-\left(\tilde{G}_{LH}\right)^2>0$ which is the determinant of the second principal minor. Next differentiating totally the first order conditions delivers the following system of equations of three unknowns:

$$\begin{pmatrix} \tilde{G}_{LL} + p\tilde{F}_{LL} & \tilde{G}_{LH} & -p\tilde{F}_{LK} \\ \tilde{G}_{HL} & \tilde{G}_{HH} & 0 \\ -p\tilde{F}_{KL} & 0 & p\tilde{F}_{KK} \end{pmatrix} \begin{pmatrix} d\tilde{L}/dr \\ d\tilde{H}^{G}/dr \\ d\tilde{K}/dr \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix}$$

The Cramer's rule allows deriving the optimal responses to changes *dr*:

$sign\dfrac{d\tilde{L}^{G}}{dr} = -sign\left(-p\tilde{G}_{HH}\tilde{F}_{LK}\right)$ which is positive

$sign\dfrac{d\tilde{H}^{G}}{dr} = -sign\left(-p\tilde{G}_{HL}\tilde{F}_{LK}\right)$ which is positive

$sign\dfrac{d\tilde{K}}{dr} = -sign\left(\left(\tilde{G}_{LL} + p\tilde{F}_{LL}\right)\tilde{G}_{HH} - \left(\tilde{G}_{LH}\right)^{2}\right)$ which is negative by the second order sufficient condition

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