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The real effective exchange rate and deforestation

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The real effective exchange rate and deforestation

"La forêt ici manque et là s'est agrandie"
Victor Hugo
Les Rayons et les Ombres

Abstract. Based on an annual sample of 122 countries over the 1963-1994 period, this paper shows that real exchange rate depreciation reduces deforestation in relatively developed countries (with GDP per capita greater than $900) whereas it has the opposite effect in poor countries. A possible explanation for this result lies in the hypothesis that variations in the real exchange rate are perceived as being transitory in LDCs, given its high degree of instability in these countries. Our empirical results suggests that macroeconomic policy is a potentially important determinant of environmental outcomes.

Keywords: deforestation, real effective exchange rate.

JEL: O13, Q23, F31, F41

Résumé. Cet article montre, en se basant sur un échantillon d'observations annuelles relatives à 122 pays pour la période 1963-1994, que la dépréciation du taux de change réel favorise le boisement dans les pays relativement développés (avec un PIB par tête supérieur à 900 dollars), alors qu'elle est un facteur de déforestation dans les pays pauvres. Ce résultat pourrait s'expliquer par l'hypothèse selon laquelle, dans les pays pauvres (contrairement aux pays riches), les variations du taux de change réel sont généralement considérées comme transitoires, compte tenu de la forte instabilité de celui-ci. Il suggère que la politique macroéconomique a une certaine portée en ce qui concerne l'évolution de l'environnement.

mots clé : déforestation, taux de change effectif réel

1. INTRODUCTION

The links between the environment and the process of economic development are usually held to involve structural variables, such as demographic factors, with relative prices playing an insignificant role. One of the aims of this paper is to redress this imbalance, by examining the impact of the real effective exchange rate on deforestation,

Forests are not only a natural resource, but also an internationally traded good. It follows that one would expect an impact on forest coverage of the real effective exchange, given that it represents the relative price of tradables. Figure 1 presents the mean rate of forestation (the difference in logarithms of forest coverage, expressed in thousands of hectares), for 122 countries over the 1963-1994 period, with one-standard deviation confidence bands. The average rate of forestation is highly variable, and the one-standard deviation confidence bands are quite broad. In Figure 2 we carry out the same exercise for the real effective exchange rates of the same sample of countries. On average, there has been a tendency for the currencies included in the sample to depreciate, and the dispersion has been even wider than for the rate of forestation. At a heuristic level, the high degree of variation across time, and the high dispersion across countries, suggests that analysis of the relationship between these two variables using panel data techniques could be fruitful.

Many papers have considered the determinants of deforestation, though only one recent paper (Bhattarai and Hammig, 2001) includes macroeconomic policy. Bhattarai and Hammig consider the environmental Kuznets curve hypothesis (an inverted-U relationship linking per capita GDP to the rate of deforestation), but neglect the impact of the real exchange rate, despite the fact that it is one of the main side-products of macro policy. Our paper differs from their's in two respects. First, we explicitly consider the dynamics of deforestation, which we model as a first-order difference equation. Just as it is appropriate to write a conventional growth of GDP per capita equation while allowing for convergence effects through the inclusion of the initial level of GDP per capita, one should include the initial level of forest coverage as an explanatory variable.

Second, we focus on the real exchange rate as a key indicator of short-run macroeconomic policy, in preference to foreign indebtedness or the premium on the black market for foreign exchange. In the long run, the real exchange rate is determined by the level of development through the Balassa-Samuelson effect. The relationship linking the real exchange rate to the rate of deforestation therefore reflects both macro policy and the level of economic development. An environmental Kuznets curve that would be divorced from the real exchange rate would therefore be hard to identify empirically.

This paper is organized as follows. We begin by presenting the basic theoretical model, with particular emphasis on dynamic aspects. We then analyze the main transmission mechanisms through which the real exchange rate impacts the rate of deforestation, and explain why we expect it to be a key determinant alongside traditional factors such as demographic variables. Finally, we present our empirical results, based on estimation using country-specific fixed effects on a panel of 122 countries over a thirty year time span.

2. BASIC SPECIFICATION AND DYNAMICS

Let the dynamic process followed by forest coverage per capita be given by :

$$(1) \qquad f_{it} - f_{it-1} = f_{it-1}\beta + z_{it}\alpha + \varepsilon_{it}$$

where f_{it} represents the logarithm of forest coverage per capita in country i at time t, z_{it} is a matrix of exogenous factors, including the real effective exchange rate, β and α are parameters, and ε_{it} represents the usual disturbance term. The main differences between our specification and that chosen by Bhattarai and Hammig (2001) is that they impose the restriction $\beta = 0$ and exclude the real effective exchange rate from z_{it}. Imposing the steady-state condition ($g_{it} = f_{it} - f_{it-1} = 0$) yields a steady-state level of forest coverage per capita in country i at time t, for given values of z_{it}, of :

$$f_{it}^{*} = -z_{it}\hat{\beta}^{-1}\hat{\alpha} .$$

Here, $\hat{\beta}$ and $\hat{\alpha}$ represent parameter estimates that will be obtained through our estimation procedure. The usual dynamic stability condition for a scalar system is given by:

$$0 < \left| \left. \frac{df_{it}}{df_{it-1}} \right|_{f^*} \right| < 1,$$

which is equivalent here to $-1 < \hat{\beta} < 0$ or $-2 < \hat{\beta} < -1$.

If we let $f_{it} = F_{it} - P_{it}$ where F_{it} is the logarithm of forest coverage (in hectares), and P_{it} represents the logarithm of the population, equation (1) can be rewritten as:

$$\text{(2)} \qquad F_{it} - F_{it-1} = F_{it-1}\beta + \left(P_{it} - P_{it-1}\right)(1+\beta) - P_{it}\beta + z_{it}\alpha + \varepsilon_{it}$$

The real exchange rate will play two roles in the analyses that follow. First, it will potentially have an impact on the rate of deforestation, while controlling for the initial level of forest coverage. Second, it will have an impact on the steady-state level of forest coverage. This second effect results mechanically from a correctly-posed dynamic specification. Both of these effects are missing from the results presented by Bhattarai and Hammig (2001).

More complex specifications are, of course, possible. A cubic specification is given by :

$$\text{(3)} \qquad f_{it} - f_{it-1} = f_{it-1}\beta + f_{it-1}^{2}\gamma + f_{it-1}^{3}\delta + z_{it}\alpha + \varepsilon_{it}\ .$$

In what follows, we will confine our attention to polynomials of order three, first because they are analytically tractable and, second, because our empirical work revealed that polynomials of higher order changed nothing of significance in our empirical findings. The existence of three real roots, and therefore the absence of cyclical behavior, can easily be tested using the specification given by equation (3), by computing the empirical counterpart to the discriminant of the system.[1]

[1] Rewriting equation (3) allows one to characterize the steady-state implicitly by : $f_{it}^{*3}+f_{it}^{*2}\hat{\delta}^{-1}\hat{\gamma}+f_{it}^{*}\hat{\delta}^{-1}\hat{\beta}+z_{it}\hat{\delta}^{-1}\hat{\alpha}=0$. In the Appendix, we give the conditions that allow one to test for the absence of cyclical steady-state behavior. A graphical illustration of a solution with three real roots, of which one is positive, is given in Figure 1.

3. The real exchange rate as a determinant of deforestation

The real exchange rate and long-run forest management

Given that forests are, in the long-run, a renewable resource, forest coverage is a function of its long-run rate of return. Thus, the expected real price of wood products in a given country is one of the determinants of the present value of forests and stimulates investment in the latter. Since wood is a tradable good, its real price will increase following a depreciation of the real exchange rate. If this depreciation is considered to be permanent, it follows that deforestation will be reduced. This effect of the real exchange rate depends, however, on the hypothesis that the forest is not a common property resource, and is therefore a function of the state of property rights.

Short-run depreciation and deforestation

In contrast to the previous discussion, a depreciation that is considered to be a short-run phenomenon could result in a temporary increase in the rate of deforestation. There are four manners by which this effect can obtain.

First, a depreciation in the real exchange rate increases the relative price of exported timber: deforestation may then increase in order to serve the export market. Second, such a depreciation increases the return to timber-consuming activities that produce internationally traded goods (such as paper or furniture). This is true whether the goods in question are destined for the export market or compete with imports. In contrast, the intermediate consumption of wood by non-traded good producing industries (such as construction) may be reduced. The increase in intermediate timber consumption stemming from tradables is likely to outweight the reduction in consumption from non-tradables, especially since the depreciation is likely to stimulate income growth, thereby increasing the demand for non-tradables.

Third, real exchange rate depreciation increases the relative price of energy (oil, gas and electricity). The use of wood for heating and cooking, particularly in rural areas, will therefore increase, especially since the opportunity cost of wood collection is not affected by the depreciation. In regions where property rights are poorly defined and where forest coverage is sparse, such as the African Sahel, this increase in harvesting can often lead to severe deforestation. Finally, real exchange rate depreciation increases the return to agricultural activities, irrespective of whether these are constituted by export or food crops (some of which may compete with imported products), and leads to clearing with the goal of bringing additional agricultural land into production.

The first and second effects of real exchange rate depreciation should be operative in humid tropical regions, the third in the Sahel, whereas the fourth is not specific to any geographic zone in particular. Following the devaluation of the CFA Franc, for instance, heavy timber traffic on roads in Gabon increased, domestic furniture production boomed in Abidjan and Dakar, carts carrying firewood prolifered in rural Burkina Faso, and clearing obtained almost everywhere. Similarly, after the collapse of the Indonesian Rupiah in 1997, timber exports increased and wood was substituted for petroleum products for domestic use.

In summary, real exchange rate depreciation leads to deforestation when the forest is a common property resource or when the depreciation is perceived as being transitory. It reduces deforestation only when the depreciation is perceived as being permanent and when property rights and forest-management practices are well-established. It follows that the deforestation effect of a depreciation should dominate in developing countries while the opposite should be true in developed countries. This is especially probable because of the greater variability of real exchange rates in the developing world, which leads to a more widely-held perception of the transitory nature of depreciations. The deforestation effect is exacerbated by endemic poverty, poorly-defined property rights and a high rate of time preference.

The preceding discussion suggests rewriting equation (1) as follows :

$$(4) \qquad f_{it} - f_{it-1} = f_{it-1}\beta + z_{it}\alpha + \rho r_{it} + \gamma r_{it} y_{it} + \xi y_{it} + \varepsilon_{it}, \ \ \rho > 0, \gamma < 0 ,$$

where r_{it} represents the real exchange rate in country i at time t (a decrease in r_{it} corresponds to a real depreciation), y_{it} is real GDP per capita, and z_{it} is a vector of other exogenous variables. The assumptions on the parameters implies that a real depreciation increases deforestation for low levels of GDP per capita, and decreases it once a certain threshold level of GDP per capita has been crossed. Note that y_{it} has been included in linear form in the equation. We do this for two reasons: first for logical consistency in that if the marginal impact of the real exchange rate on the rate of deforestation is a function of income per capita, it is common econometric practice to allow the marginal impact of the latter variable (income per capita) also be a function of the former (the real exchange rate); second, because as income per capita increases, the share of agriculture in GDP decreases, which should reduce pressure on forests.

The Balassa-Samuelson effect and the environmental Kuznets curve

The Balassa-Samuelson effect states that the equilibrium real exchange rate appreciates as GDP per capita increases. We express this by writing:

$$(5) \qquad r_{it} = y_{it}\phi + \omega_i ,\ \phi > 0 ,$$

where ω_i is a country-specific effect. Combining equations (4) and (5) yields :

$$(6) \qquad f_{it} - f_{it-1} = f_{it-1}\beta + z_{it}\alpha + y_{it}\left(\rho\phi + \gamma\omega_i + \xi\right) + y_{it}^2\gamma\phi + \rho\omega_i + \varepsilon_{it},\ \gamma\phi < 0 .$$

Equation (6) involves a quadratic effect of GDP per capita which would correspond to an *inverted* environmental Kuznets curve when $\rho\phi + \gamma\omega_i + \xi > 0$ (given that the coefficient $\gamma\phi$ associated with y_{it}^2 is negative). If, aside from exchange rate effects, there are reasons to expect an environmental Kuznets curve, it may be obscured by the inverted Kuznets curve generated by the real exchange rate, if the real exchange rate is not explicitly included as an explanatory variable in the empirical specification.

Other covariates

The real exchange rate is a determinant of deforestation in that it represents the relative price of tradables. Given that forests also constitute a capital good, the real interest rate should be taken into account, as should the relative price of agricultural products, the latter having an impact on the value of arable land.

The expected return to forest acreage can be expressed as the product of the real interest rate (θ) by the present-discounted-value of harvestings (V). This expected rate of return corresponds to the rental rate that the owner of the forest could obtain (Conrad, 1999). When the interest rate increases and the increase is considered permanent, θV decreases since, though θ rises, V decreases in an exponential manner. An increase in the real interest rate should therefore reduce forest coverage.

Forest renewal is an extremely long-term process. It follows that it would be most appropriate to use a long-term interest rate. Such an interest rate is, however, unavailable for most developing countries. Short-term interest rates, which are available for some countries in our sample, are highly variable and do not constitute an adequate proxy for the expected long term real interest rate. To the extent that international capital mobility tends to equalize real interest rates internationally, and that changes in the level of the real interest rate over time will be accounted for by year dummies, the omission of the real interest rate from the specification is not likely to pose serious problems. Moreover, between-country differences in the return to capital are likely to be linked to differences in GDP per capita, which is already present in the specification. We approximate the third relative price that should be included in the specification —the price of timber relative to other agricultural products that could be grown on the same land— by using the ratio of the price of wood from all sources quoted in London to the country-specific unit export values of agricultural goods.

As shown in equation (2) both the level and the rate of growth of the population should be included in our specification. This obtains because our point of departure is forest area per capita: the inclusion of these two demographic variables arises for purely mechanical reasons. Note, however, that there exists a vast litterature that considers the impact of demographic factors on deforestation, in their own right. The findings of this literature are ambiguous and sometimes contradictory. For example, population growth is often held to increase deforestation, although it is often also posited that, beyond a certain threshold, it induces technological change in agriculture that slows the process (Myers, 1994, Templeton et Scherr, 1999, cited by Bhattarai et Hammig, 2000). The empirical counterpart to these two effects involves a quadratic specification in the rate of population growth. For the same reasons, we also include the level of population (in logarithms), in quadratic form. Note that the technological change effect would appear to correspond to the Boserup (1965) hypothesis, although the latter would be more adequately tested through a quadratic specification involving rural population density.

Finally, in order to allow for an environmental Kuznets curve, we allow for a quadratic term in GDP per capita. Given that the specification already includes the real exchange rate, the appearance of an environmental Kuznets curve should not be hindered by the Balassa-Samuelson effect.

4. RESULTS

Data sources

Our dependent variable is the growth rate (the difference in logarithms) of forest area, expressed in thousands of hectares, when forest area is strictly positive (source: FAO). We do not adopt the procedure followed by Bhattarai and Hammig (2001), who limit their analysis to countries with more than one million hectares of forest. We see no reason to exclude a plethora of small countries that are often quite open to international trade, and whose forest statistics are not necessarily worse than those of other countries.[2]

The real exchange rate of country i is approximated by the real *effective* exchange rate computed as:

$$r_{it} = \prod_{j=1}^{j=10} \left(e_{ijt} \frac{p_{it}}{p_{jt}} \right)^{\alpha_j}$$

where e_{ij} is the nominal exchange rate index of country i versus country j (expressed in terms of foreign currency), p_i is the consumer price index in country i (and similarly for p_j), α_j represents the share in country i's imports furnished by country j, and where the j s are constituted by the ten most important (non-oil) trading partners of country i (these shares

[2] Our econometric results remain virtually unchanged if we adopt Bhattarai and Hammig's (2001) sample restriction.

are given by the average values for the period 1980-6; the source for all these data is the IMF).[3]

The relative price of timber is approximated by the ratio of the price of wood from all sources quoted in London (source: IMF) to the country-specific unit export values of agricultural goods (source: FAO). Other covariates, such as GDP per capita, the population, the population growth rate, and rural population density are from the World Bank's *World Tables*.

Econometric specification and results

It is hard to imagine deforestation as being a process that follows a similar pattern in all those countries included in our sample. It follows that deforestation will be a function of certain country-specific characteristics that our not controlled for by the explanatory variables included in our specification. Consider equation (1):

$$f_{it} - f_{it-1} = f_{it-1}\beta + z_{it}\alpha + \lambda_i + \upsilon_{it},$$

where we decompose the disturbance term into two parts: a first part λ_i that is country-specific and time-invariant, and a second component υ_{it} that satisfies the usual Gauss-Markov assumptions. Estimating this equation by OLS necessarily leads to bias in that z_{it} will be correlated with the composite error term $\varepsilon_{it} = \lambda_i + \upsilon_{it}$ which includes λ_i. The usual solution to this problem is to apply the within transformation.

Our econometric results, obtained after the within transformation, are presented in Table 2. In columns (1) to (3) we estimate our basic specification while including different control variables discussed above. In columns (4) and (5), we attempt to uncover an environmental Kuznets curve.

[3] Note that, when p_{it} or p_{jt} were missing, they were replaced by the domestic GDP deflator.

In column (1), note that $\hat{\rho} > 0$, $\hat{\gamma} < 0$: the point estimates imply that a depreciation in the real effective exchange rate reduces the rate of deforestation (since $\partial(f_{it} - f_{it-1}) / \partial r_{it} = \rho + \gamma y_{it}$) when GDP per capita (expressed in constant 1995 dollars) is greater than 919 US$, which corresponds roughly to the threshold below which a country was deemed to be a "low income country" at that time. Note that this result is extremely robust to introducing additional covariates (as shown by the results presented in columns 2 and 3), and that approximately one third of the countries in the sample correspond to values of GDP per capita below 919 US$ for which a depreciation increases the rate of deforestation.

With respect to the demographic variables, note that the population growth rate displays a quadratic form (with a U-shape in terms of its impact on deforestation), and that the p-values associated with the coefficients are extremely small. The threshold beyond which population growth begins to have a negative marginal effect on the rate of growth of forest area is equal to 2.4. This threshold level remains unchanged when other controls are included, and remains so in all of the specifications presented in the Table. The same can be said for the logarithm of population (the threshold is near 20 million inhabitants). The inverted-U-shape, in terms of its impact on deforestation, is sharply defined, and suffers from little modifications when the specification is changed.

For all of the specifications presented in the Table, we estimate the value of the discriminant of the cubic specification ($\hat{\Delta}$), as well as the value of $(df_{it} / df_{it-1})\big|_{f^*}$. In all cases, one readily rejects the null hypothesis of cyclical dynamics (that is, it is always the case that $\hat{\Delta} < 0$), as one rejects the null of dynamic instability (i.e., it is always true that $(df_{it} / df_{it-1})\big|_{f^*} \in (-1, 0)$). Computing the estimated value of the steady-state level of forest coverage per capita reveals that most of the countries in our sample are relatively close to f_{it}^* (with the mean deviation coming in at 2%), although a number of countries may face severe deforestation problems during convergence towards steady-state (the opposite is true for a number of other countries). All of the parameters estimates corresponding to the dynamics (the parameters associated with the initial level of forest coverage) remain virtually unchanged in the results presented in the Table.

The results presented in column (2) show that rural population density, in quadratic form, is not a significant determinant of deforestation, whereas the results presented in column (3) (in a slightly reduced sample) show that the relative price of timber and the export price of agricultural products are not statistically significant; all other coefficients remain unchanged.

Figure 4 plots the marginal impact the real effective exchange rate on the rate of forestation, for different values of GDP per capita, based on the parameter estimates presented in column (1) of Table 2. For values of GDP per capita below the threshold level of \$919 (which corresponds to 6.823 in logarithms), the marginal impact is positive, meaning that a real appreciation increases the rate of forestation. The opposite obtains once the threshold level of GDP per capita is crossed. For example, an appreciation of 10 percent of the real effective exchange rate in a country with a GDP per capita of \$400 (6 in logarithms), which corresponds to Ghana in 1999, the rate of forestation will be increased by ($0.00245 \times 0.10 =$) 0.0245 percentage points. In contrast, for a country with a GDP per capita of \$4350 (8.377 in logarithms), which corresponds to Brazil, the same appreciation will decrease the rate of forestation by ($0.00462 \times 0.10 =$) 0.0462 percentage points. Given that the mean annual rate of deforestation is equal to 0.00567, these numbers are far from being negligible.

In columns (4) and (5), we test for the presence of an environmental Kuznets curve. In column (4), the real effective exchange rate is dropped from the equation, while it remains in the results presented in column (5), as does the real effective exchange rate multiplied by GDP per capita (as in column (1)). As was predicted by our theoretical arguments, dropping the real effective exchange rate does not lead to the appearance of an environmental Kuznets curve. In column (5), however, an environmental Kuznets curve does obtain, with a squared term (which is common to all countries) which is significant at the 6.5 percent level of significance, and a country-specific linear term which is statistically significant (at the 10 percent level of confidence) for 22 countries (it is statistically indistinguishable from zero for the remaining countries in the sample). An environmental Kuznets curve therefore obtains for 22 countries in oursample, whereas for the bulk of countries, the marginal impact of GDP per capita on the rate of forestation is positive. The coefficients associated with dynamics all remain stable, as do the coefficients associated with the demographic control variables.

5. Concluding remarks

The determinants of the process of deforestation are undoubtedly much more complex than those that have been singled out in the empirical model presented in this paper. Our approach does have the merit, however, of focusing on a number of fundamental hypotheses, hitherto ignored by the empirical literature on the subject, which should condition our understanding of the process. First, the dynamics of deforestation need to be modeled explicitly and the possibility of convergence to a steady-state level of forest coverage per capita must be taken into account: this dynamic behavior constitutes the basic framework within which all other hypotheses should be tested. Second, the demographic control variables considered in this paper have complex impacts on deforestation, as highlighted by the quadratic specifications we have adopted. Third, there appears to be a weak empirical basis for an environmental Kutznets curve, with such behavior obtaining for only 20 percent of the countries in our sample.

The main finding of this paper involves the impact of the real effective exchange rate on deforestation: our econometric results do not reject the null hypothesis that a real depreciation increases deforestation in poor countries and decreases deforestation in rich countries. Given that economic policy over the past two decades has tended to favor real depreciation in the developing world (versus the developed world), it has tended to exacerbate the process of deforestation.

In the long run, it is likely that the major determinant of forestation at the global level will be constituted by the relative rates of growth of the developing and developed worlds, and the impact that this process will have on real exchange rates. If convergence obtains, real effective exchange rates will appreciate in poor countries and depreciate in rich countries, leading to a reduction in deforestation. On the other hand, an increase in inequality at the international level (divergence) will lead to a depreciation of the real effective exchange rates of the developing world, leading to an increase in deforestation.

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APPENDIX : ABSENCE OF CYCLICAL BEHAVIOR

The point of departure is the implicit characterization of the steady-state :

$$f_{it}^{*3} + f_{it}^{*2}\hat{\delta}^{-1}\hat{\gamma} + f_{it}^{*}\hat{\delta}^{-1}\hat{\beta} + z_{it}\hat{\delta}^{-1}\hat{\alpha} = 0 .$$

Following a change of variables of the form $f_{it}^{*} = x_{it}^{*} - (\hat{\delta}^{-1}\hat{\gamma}/3)$, we obtain:

(7) $$x_{it}^{*3} + \hat{a}x_{it}^{*} + \hat{b}_{it} = 0,$$

where $\hat{a} = \hat{\delta}^{-1}\hat{\beta} - 3\hat{\delta}^{-2}\hat{\gamma}^{2}/9$ and $\hat{b}_{it} = 2(\hat{\delta}^{-1}\hat{\gamma}/3)^{3} - \hat{\delta}^{-1}\hat{\beta}(\hat{\delta}^{-1}\hat{\gamma}/3) + z_{it}\hat{\delta}^{-1}\hat{\alpha}$. The usual discriminant for a cubic system is then given by $\hat{\Delta} = 4\hat{a}^{3} + 27\hat{b}_{it}^{\,2}$. When $\hat{\Delta} < 0$, there will be three distinct real roots. Moreover, Cardano's formula allows one to compute the steady-state values, which will all satisfy:

(8) $$x_{it}^{*} = \left[-\frac{\hat{b}_{it}}{2} + \frac{1}{2}\sqrt{4\hat{a}^{3} + 27\hat{b}_{it}^{\,2}}\right]^{1/3} + \left[-\frac{\hat{b}_{it}}{2} - \frac{1}{2} - \frac{1}{2}\sqrt{\frac{4\hat{a}^{3} + 27\hat{b}_{it}^{\,2}}{27}}\right]^{1/3} .$$

(Note that several other values of y^{*} will satisfy equation (8), but that only three will be able to simultaneously satisfy (7) and (8)). From the computation standpoint, this procedure is easily implementable, in contrast to polynomials of order 4. This is particularly true in terms of computing the standard errors associated with the steady-state values of the forest coverage. The stability conditions are given by the same expression as for the linear case. For the quadratic case, the dynamics will be given by: $f_{it} - f_{it-1} = f_{it-1}\beta + f_{it-1}^{2}\gamma + z_{it}\alpha + \varepsilon_{it}$. The steady-state values (one of which will potentially be negative if additional restrictions are not imposed) will then be given by:

$$f^{*} = \frac{-\hat{\beta} \pm \sqrt{\hat{\beta}^{2} - 4z_{it}\hat{\gamma}\hat{\alpha}}}{2\hat{\gamma}},$$

whereas the stability condition will be given by:

$$0 < \left|(df_{it}/df_{it-1})\right| = \left|1 \pm \sqrt{\hat{\beta}^{2} - 4z_{it}\hat{\gamma}\hat{\alpha}}\right| < 1 .$$

Note that a negative discriminant $\hat{\beta}^{2} - 4z_{it}\hat{\gamma}\hat{\alpha} < 0$ will imply cyclical behavior by f_{it}. We shall exclude such a quadratic specification for two reasons. First, because a quadratic specification with an unstable upper steady-state implies unbounded forest growth if exogenous shocks lead the system above that level. Second, because the quadratic specification is always rejected in favor of the cubic alternative in our empirical results.

Figure 1 . The average rate of forestation, 1963-1994

Figure 2
The average real effective exchange rate, 1963-1994

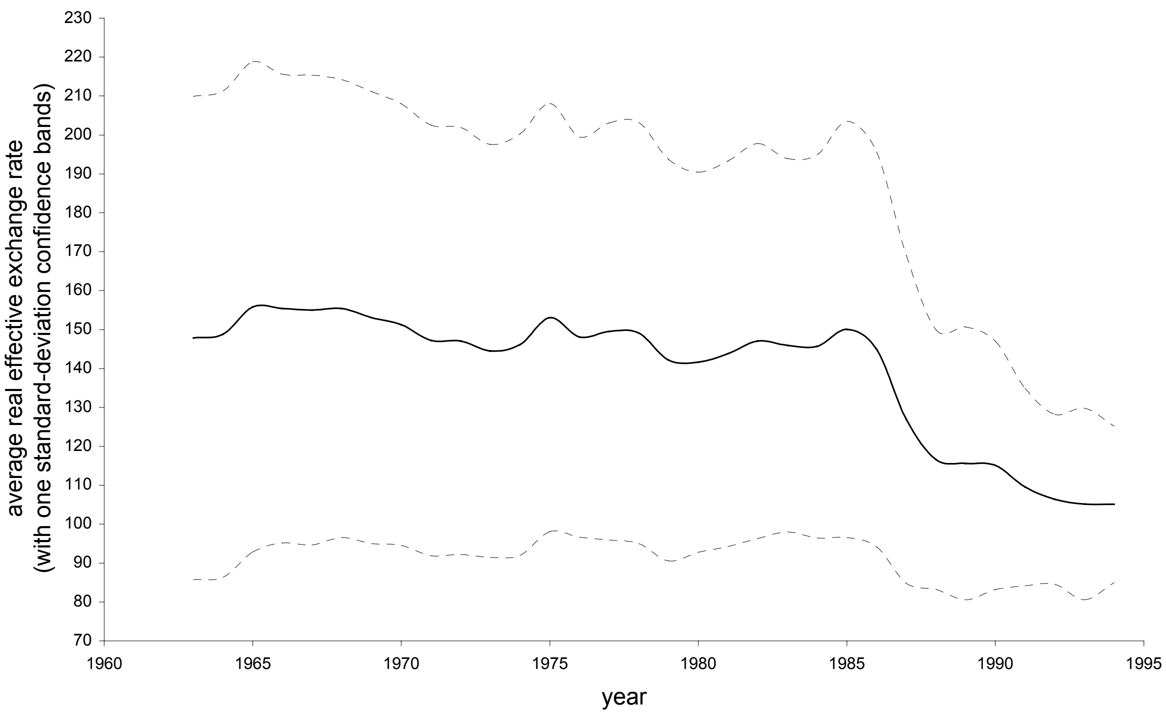

Figure 3
A cubic system with a stable positive steady-state

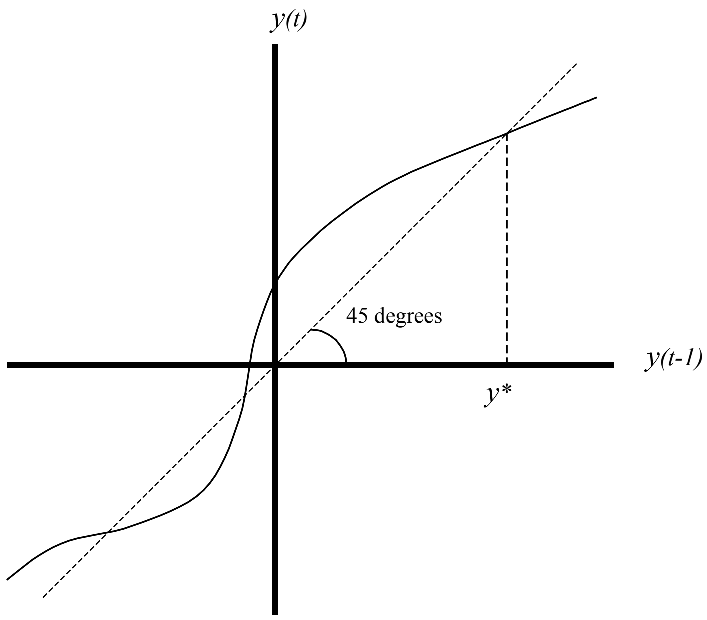

Figure 4. The marginal impact of the real effective exchange rate on the rate of forestation, as a function of GDP per capita

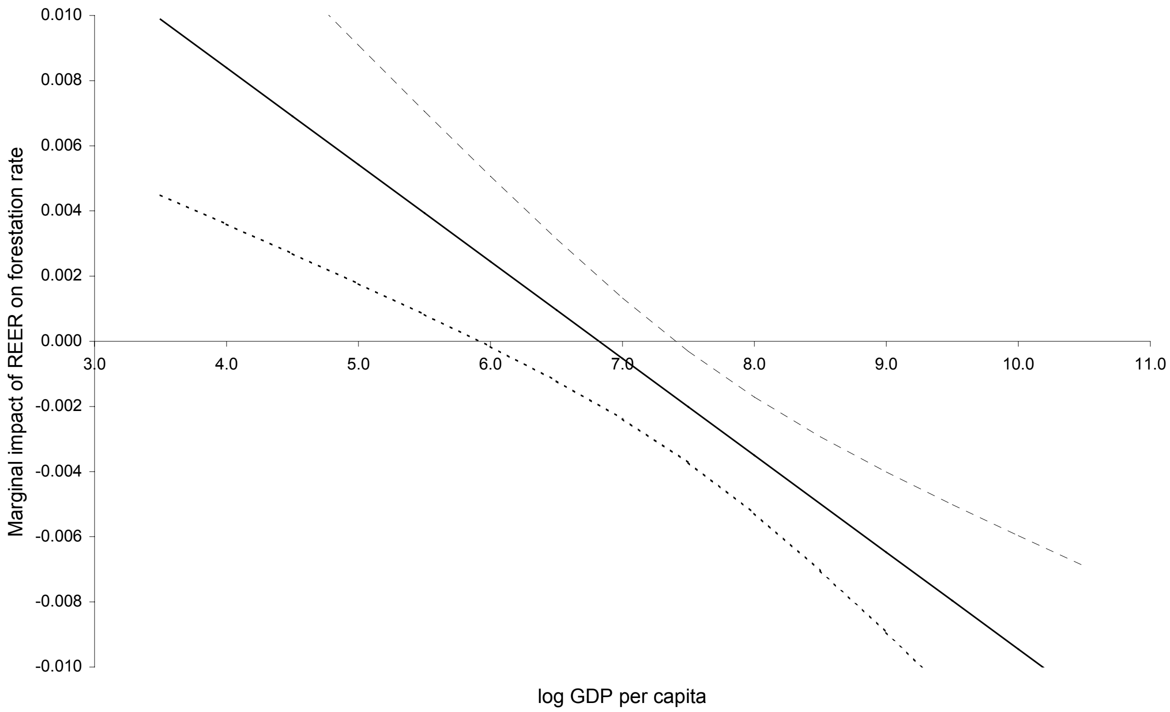

Table 1
Descriptive statistics
(1962-94, 122 countries, unbalanced panel, 3233 observations)

	Mean	Median	Standard deviation
Rate of forestation	-0.00567	0.000	2.62
Log forest coverage (in thousands of hectares)	7.941	8.542	2.751
Real effective exchange rate	136.3	125.2	49.0
GDP per capita	5486	1640	8074
Population growth rate	2.084	2.231	1.367
Log of population	15.544	15.555	1.830
Rural population density	529	224	1436
Relative price of timber to agricultural exports	0.353	0.365	0.659

Note: for the relative price of timber, the descriptive statistics correspond to a slightly reduced sample of 3192 observations.
Sources: forest coverage and unit price of agricultural exports (FAO), GDP per capita, population, rural population density (World Bank), nominal exchange rate, consumer price index and price of timber (IMF).

Table 2. Determinants of the rate of forestation:
Country-specific fixed effects
(dependent variable : rate of growth of forest coverage, in thousands of hectares, 1962-94, 122 countries, unbalanced panel, p-values below coefficients)

	(1)	(2)	(3)	(4)	(5)
Dynamics					
Log forest_{t-1}	-0.482	-0.484	-0.481	-0.486	-0.622
	0.000	0.000	0.000	0.000	0.000
$(\text{Log forest}_{t-1})^2$	0.061	0.062	0.061	0.062	0.073
	0.000	0.000	0.000	0.000	0.000
$(\text{Log forest}_{t-1})^3$	-0.002	-0.002	-0.002	-0.002	-0.003
	0.000	0.000	0.000	0.000	0.000
Real effective exchange rate					
Log REER	0.020	0.019	0.002		0.036
	0.036	0.047	0.026		0.002
(Log REER) × (Log GDP per capita)	-0.003	-0.003	-0.003		-0.004
	0.018	0.024	0. 014		0.001
Threshold level (GDP per capita) of marginal effect of REER	919.4		1051.8		1730.5
	0.127		0.100		0.009
Environmental Kuznets curve					
Log GDP per capita	0.012	0.011	0.013	0.0005	
	0.053	0.073	0.035	0.965	
Log GDP per capita × ω_i					See note
(Log GDP per capita)^2				-0.0001	0.011
				0.859	0.065
Other determinants of steady-state level of forest coverage per capita					
Population growth rate	0.002	0.002	0.002	0.002	0.004
	0.018	0.017	0.018	0.023	0.000
(Population growth rate)^2	-0.0004	-0.0004	-0.0004	-0.0004	-0.0009
	0.000	0.000	0.000	0.000	0.000
Log population	-0.070	-0.073	-0.070	-0.070	-0.085
	0.003	0.002	0.003	0.003	0.035
(Log population) ^{2}	0.002	0.002	0.002	0.002	0.002
	0.006	0.003	0.006	0.004	0.024
Rural population density		-0.2×10^{-5}			
		0.368			
(Rural population density) ^{2}		0.1×10^{-9}			
		0.349			
Relative price of timber to agricultural exports			0.001		
			0. 246		
Threshold level of population growth	2.471	2.471	2.608	2.440	2.419
	0.002	0.002	0.002	0.003	0.000
Hausman test: fixed effects *versus* random effects : p-value	0.000	0.000	0.000	0.000	0.000
H_0 : cyclical steady-state ($\hat{\Delta}>0$, p-value)	0.000	0.000	0.000	0.000	0.000
H_0 : unstable steady-state (p-value)	0.000	0.000	0.000	0.000	0.000
$\bar{R}^2$	0.239	0.238	0.240	0.237	0.284
No. of observations	3233	3233	3192	3233	3233

Note: year dummies included in all specifications. In column (5), the coefficients associated with log GDP per capita are country-specific. Out of 120 of these coefficients, none is positive and statistically significant, whereas 22 are negative and statistically significant at the 10 percent confidence level.