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## Trade liberalisation and global-scale forest transition

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**Abstract:** In this paper, we develop a theoretical model that provides an additional explanation for the forest transition based on a trade liberalisation scenario. Furthermore, in contrast with most explanations, in which the forest transition can only take place at a local level at the expense of other areas, ours is capable of supporting such phenomenon at a worldwide level. We introduce a renewable natural resource (wood), used as an input by manufacturing firms, in a framework with economic geography foundations: transport costs affect the distribution of firms between countries. In a general equilibrium, the results reproduce the forest transition at a global scale: a decrease in transport costs (in particular, that of the natural resource) has a negative effect on the worldwide stock of the natural resource in the short-term; however, this effect is offset during the transition as a consequence of industrial reallocation between countries and eventually disappears in the long-run.

**JEL classification:** F18, Q20, Q23, R12

**Keywords:** Forest transition, natural resources, industrial location, trade liberalisation

## 1. Introduction

There is an extensive literature on the effects of trade liberalisation on natural resources. A general conclusion might be that an increasing openness to international trade (basically represented by the fall in international transport costs, although changes in other trade policy measures are also important) increases the specialisation of different countries. Therefore, those with comparative advantages in natural resources increase their natural condition as suppliers of these resources to the rest, who specialise in industrial activities. This is the typical result of the theory of international trade: liberalisation leads to specialisation (complete, as in Ricardo's world, or incomplete, as in Krugman, 1980).

Among all natural resources, the effect on forest areas has received much attention in the literature -see the review by Robalino and Herrera (2009). In the context of growing environmental concerns, the loss of forest area has emerged as a problem in many developed countries. The growth of economic activity requires increasing amounts of resources (land, timber, etc.). To the extent that they are not renewable or that their regeneration is relatively slow, one might expect a gradual depletion of these resources.

However, recent data offer partial good news. After several decades of a continuous decrease in forest areas all over the world, the rates of deforestation have diminished in many countries over recent years. One of the key findings of the last Global Forest Resources Assessment (2010) was that "the rate of deforestation shows signs of decreasing", although it is still high. Figure 1 shows the annual rates of change in the forest areas of different regions based on data from FAOSTAT. The left graph displays the evolution in world rates and in the rates of the Americas (North America, Central America, South America and the Caribbean). The Americas represented 39% of the worldwide forest area in 2008. We can observe that, although growth rates remain negative, there has been a remarkable decrease in deforestation rates both at world and at American levels in recent years. The right graph highlights the Brazilian case, where a growing evolution in rates is also observed. Brazil represented 13% of the total forest area in the world in 2008 and the Brazilian Amazon is one of the most important cases of study. Obviously, this evidence is weak as the data span considered is very short, only from 1990 to 2008. However, there are several papers that document this forest change in different areas: Finland (Myllyntaus and Mattila, 2002), India (Foster and

Rosenzweig, 2003), Southeastern Mexico (Bray and Klepeis, 2005), the Ecuadorian Andes (Farley, 2010), the Ecuadorian Amazon (Rudel et al., 2002) and Northeastern United States (Pfaff and Walker, 2010).

This change in the trend from decreasing to expanding forests was defined as the forest transition by Mather (1992), which suggests the existence of a turning point. Therefore, the forest transition theory (FTT) provides a framework for explaining scenarios of increasing forest cover after a decreasing phase. That is to say, although in the first stage economic activity needs a growing volume of natural resources and this thus causes the depletion of forests, at some point the trend reverses, allowing the recovery of the forest area. The argument can also be formulated in terms of the Environmental Kuznets Curve -see Pfaff and Walker (2010).

Many papers (Pfaff, 2000; Andersen et al., 2002; Weinhold and Reis, 2004; Pfaff and Walker, 2010) point to increased transport easiness (through reductions in costs or liberalisation of international trade) as one of the most important causes of the change in this trend, as a consequence of the reallocation of economic activity. Kastner et al. (2011) use FAOSTAT data on wood trade flows between 172 nations from 1997 to 2007 and conclude that, in many settings, wood imports speed up forest return considerably or even enable it, although with regards to the potential of global forest return, this result implies that it may be lower than national trajectories suggest. However, empirical studies testing the relationship between trade openness and deforestation are scarce.

Therefore, although the effect of a decrease in transport costs in the short-term is an increase in deforestation because access to the forest area becomes easier (Chomitz and Gray, 1996; Pfaff, 1999; Ali et al., 2005; Pfaff et al., 2007), in the long-term this effect can be reversed because of the reduction in transport costs changes the geographical organisation of economic activity. Furthermore, this shift has multiple dimensions, related with relative prices, land use, increasing returns to scale or migrations.

First, if liberalisation reduces the relative price of a resource, then a shift in production will occur in developed countries towards more profitable activities at the expense of natural resource exploitation. Second, given that agriculture is a land-intensive activity, if the increase in trade also leads to a fall in agricultural prices, this will cause a shift of activity from agriculture to industry or services activities, and these

sectors are less land-intensive (land use theory; Rudel et al., 2005). Third, the existence of increasing returns to scale in the manufacturing sector enhances the benefits of specialisation in these activities compared with the primary sector, which promotes the productive change. Finally, changes in the productive structure produce a concentration of the population through regional migrations (farm population tend to be more dispersed), favouring the growth of the forest area (Carr, 2009).

Other causes of this shift in forest trends (Pfaff and Walker, 2010) can include the growth of productivity in the agricultural sector (which reduces the pressure on arable land), energy diversification (which reduces energy-dependence on wood fuel) and changes in the preferences of individuals, increasingly concerned about the preservation of nature.

However, all these reasons that support the FTT have a critical shortcoming, as exposed by Rudel et al. (2005) and Pfaff and Walker (2010). The spatial scale is crucial to find or not a reversal of the trend. Thus, if we go back to the reasons exposed above, all of them can explain a decrease in the pressure on specific forest areas, but at the cost of moving the pressure to other areas.

The productive specialisation (through international trade) that reduces the weight of exploitation activities in developed countries involves, by symmetry, a specialisation in these same activities in other countries (those with greater natural endowments, in our case greater forest areas). The change in land use that reduces agricultural activities is only possible if food imports from other countries increase, whereas in those other countries the change in land use is just the opposite (Meyfroidt et al., 2010). Furthermore, something similar happens to changes in environmental concerns: protectionist efforts in the closest geographical areas often result in greater exploitation in remote areas. In short, trade liberalisation boosts a forest transition in developed countries that allows an increase in their forest areas. But, to the extent that global resource requirements do not fall (if there is no technological change), this kind of transition results in the increased exploitation of other areas, that we can identify as developing countries (Chomitz and Gray, 1996; Pfaff, 1999; Ferreira, 2004; Ali et al., 2005; Pfaff et al., 2007), or even an increase in global exploitation (Rudel et al., 2005). Therefore, the scale at which forest transition might take place according these explanations is only local.

Thus, if the forest area increases in the developed countries to the detriment of a further depletion in the developing ones (Brander and Taylor, 1997a), is a global (i.e., not only local) forest transition also possible? This is the key question of our paper. In other words, although the FTT seems to suggest that the pressure on natural resources simply moves from some countries to others, might the aggregate pressure also ease off? Could we expect the worldwide forest area to recover?

In contrast with the previous arguments that support local forest transitions, but can hardly be extended to a worldwide perspective, in this paper we provide additional arguments supporting a possible global forest transition. To this end, we turn to the analytical models of the New Economic Geography, which consider explicitly the role played by transport costs. Specifically, Martin and Rogers (1995) provide a general equilibrium framework in which the trade-off between economies of scale and transport costs defines the location of economic activity. This is the most tractable of all economic geography models (see Baldwin et al., 2003, ch. 3), which is also known as the footloose capital model. In this paper, we extend this framework by including two areas (North and South) with different natural resources endowment. This allows us to analyse the impact of trade liberalisation not only on the distribution of economic activity between countries, but also on the stock of natural resources. Particularly, our model is able to reproduce the FTT dynamics, but at a global scale: a reduction in transport costs has a negative effect on the stock of natural resources in the short-term, but this initial effect is reversed in the long run as a consequence of the reallocation of industrial firms between countries.

Regarding the endowments of natural resources, we consider a completely asymmetric scenario in which the natural resource is located only in one of the two countries, namely the South. There are two reasons for this configuration. On one hand, it simplifies the analytical treatment of the model, with the results remaining qualitatively robust as long as we keep a relative abundance of natural resources in this country. On the other hand, keeping in mind that the trend observed and described by the FTT is a progressive specialisation of the South in natural resources exploitation, we consider the extreme case (the complete specialisation of the South), which is the worst scenario for a possible global forest transition. If, even there, we obtain arguments supporting a global forest transition, they should apply more easily in a more favourable scenario in which the North shares a part of the natural resource endowment. .

In a related research, Jinji (2006) also investigates the effects of trade liberalisation on deforestation using a model with an endogenous carrying capacity of the resource. He finds that, against the usual result that trade liberalisation reduces forest stocks in countries with an abundance of this natural resource (Brander and Taylor, 1997b), trade liberalisation may increase the forest stock in the resource-abundant country (and, in parallel, decrease the forest stock in the resource-scarce country). Our model offers a new complementary perspective. Although the carrying capacity in steady state does not change, the long-term change in industrial location driven by trade liberalisation finally results in a drop in global demand for the resource that allows for a recovery of the forest area in the country with an abundance of this resource.

The remainder of the paper is structured as follows. Section 2 presents the basic characteristics of the theoretical model. In Section 3 the equilibrium is obtained. Departing from this equilibrium, Section 4 analyses the effects of trade liberalisation on natural resources through a decrease in the transport cost of the natural resource, distinguishing between short and long run effects. Finally, the work ends with the conclusions.

## **2. The model**

We follow the dynamic framework proposed by Martin and Ottaviano (1999, 2001), which is an extension of the static model originally proposed by Martin and Rogers (1995), although avoiding economic growth engines. This allows us to maintain the model's tractability even after the inclusion of a new input, namely the natural resource, with its own dynamics.

We consider two countries, North and South, which trade with each other. In a broad sense, we can identify the North as the more industrialised country and the South as the natural resources abundant one. There are two key differences between them that determine this characterisation. First, the natural resource is only available in the South, carrying to the extreme the relative specialisation of the South in natural resources, which makes the model more tractable. Second, the North is more industrialised than the South, although not completely specialised, which, as will be shown, is equivalent to assume that the North is capital abundant and implies that it is also richer in terms of national income.

Given that both countries share identical characteristics otherwise, we focus on describing the economy of the North (an asterisk denotes in what follows the variables corresponding to the South). Both countries are inhabited by a symmetrical population of  $L$  representative households (both in the North and in the South) playing the part of consumers and workers. Labour is mobile between sectors but immobile between countries.

### ***Preferences***

The preferences are instantaneously nested CES and intertemporally CES, with an elasticity of intertemporal substitution equal to the unit:

$$U = \int_0^{\infty} \log(D_t^\alpha Y_t^{1-\alpha}) e^{-\rho t} dt, \quad (1)$$

with  $0 < \alpha < 1$ .  $\rho$  denotes the intertemporal discount rate,  $Y$  is a traditional homogeneous good (which we consider as the numeraire good) and  $D$  is a composite good that, in the style of Dixit and Stiglitz, consists of a number of different varieties of what we identify as manufactures:

$$D_t = \left( \int_{i=0}^N D_{it}^{1-\frac{1}{\sigma}} di \right)^{\frac{1}{1-\frac{1}{\sigma}}}. \quad (2)$$

$N$  denotes the total number of varieties available worldwide, produced either in the North ( $n$ ) or in the South ( $n^*$ ), with  $N = n + n^*$ . This specification implies the existence of a love-of-variety effect; that is to say, the utility derived from any total amount of manufactures is higher the wider the set of varieties included. The parameter  $\sigma > 1$  captures the elasticity of substitution between varieties, which (for  $N$  high enough) coincides with the price elasticity of demand for each variety.

Note that the natural resource does not appear explicitly in the structure of individual preferences, meaning that it lacks value for consumers (it might have social value, which could lead a planner to decide to maintain a minimum level, but we do not consider this possibility). The only role of the natural resource is as an essential input in the industry.

### ***Trade***

International trade between the two countries is costly, which we capture using iceberg-type transport costs (Samuelson, 1954):  $\tau$  and  $\tau_R$  units ( $\tau, \tau_R > 1$ ) of

manufactures and natural resource, respectively, must be sent from the original country for each unit that arrives at the destination. That is to say, only a fraction  $\tau^{-1} < 1$  of each unit of any variety of manufactures sent from one country is available for consumption in the other country. Similarly, the North incurs the additional transport cost associated with the natural resource: only a fraction  $\tau_R^{-1} < 1$  of each unit of the natural resource sent from the South is available for firms in the North; obviously, this cost is not borne by firms located in the South since they do not have to trade the resource. From here on, we assume  $\tau_R \leq \tau$ : it is less costly (or, at best, equal) to transport natural resource compared with manufactures<sup>1</sup>. For simplicity, we adopt the usual assumption that the traditional good is not subject to transaction costs.

### ***Traditional good sector***

The numerary good is produced using only labour, subject to constant returns in a perfectly competitive sector. As labour is mobile between sectors, the constant returns in this sector tie down the wage rate  $w$  in each country at each moment. We assume throughout the paper that the parameters of the model are such that the numerary is produced in both countries, that is, that the total demand for the numerary is big enough so as not to be satisfied with its production in a single country<sup>2</sup>. In this way, wages are constant and they are identical in both countries. A unit of labour is needed to produce a unit of  $Y$ , so free competition in the labour market implies that  $w = 1$  in both countries.

### ***Manufacturing sector (industry)***

The different varieties of manufactures are produced using identical technologies. Labour ( $L$ ) and the natural resource ( $R$ ) are combined through a Cobb–Douglas-type technology to produce  $x$  units of the  $i$ -th variety in the way:

$$x_i = L_i^{1-\mu} R_i^\mu, \quad (3)$$

where  $\mu \in (0,1)$  measures how intensive is the sector in the use of the natural resource.

As stated above, the availability of the resource only in the South makes manufacturing costs different depending on the location of the firms. From the technology of the production of manufactures (3), the variable cost of producing one

<sup>1</sup> The results are maintained even when transport cost for the resource is higher than that for the differentiated good, as long as the difference is not too great.

<sup>2</sup> The restriction on parameters that guarantees that the traditional good is produced in both countries is the same as in our reference model -see Martin and Ottaviano (1999), appendix A.

unit of any variety for a representative firm located in the South is  $\beta w^{1-\mu} p_R^\mu$ , with  $\beta = \mu^{-\mu} (1-\mu)^{\mu-1}$ , which includes the cost of labour ( $w$ ) and that of the natural resource ( $p_R$ ). In parallel, the variable cost for a firm located in the North is given by  $\beta w^{1-\mu} (\tau_R p_R)^\mu$ . In contrast to the costs of Southern firms, this incorporates the transport cost for the natural resource and, thus, the variable cost is higher than the cost incurred by any firm located in the South. In other words, firms in the South enjoy a competitive cost advantage derived from the presence of the natural resource in their territory.

The standard rule of monopolistic competition determines the price of any variety produced either in the North or in the South as a margin  $\sigma/(\sigma-1)$  over the unitary costs of production. Thus, the difference in costs translates to the prices of the varieties produced in each country, namely  $p = \frac{\sigma\beta}{\sigma-1} (\tau_R p_R)^\mu$  in the North and  $p^* = \frac{\sigma\beta}{\sigma-1} p_R^\mu$  in the South, where we have taken into account that  $w=1$ . The higher costs borne by firms in the North imply a higher price for the varieties produced in the North than that of the varieties produced in the South:  $p > p^*$ .

In order to produce a variety, a previous investment in capital is required, either in a physical asset (machinery) or in an intangible one (patent). The concept of capital  $K$  used in this paper corresponds to a mixture of both types of investment. We assume that each variety is produced by one firm and that it requires one unit of capital. On one hand, this is a fixed cost that gives rise to scale economies; on the other, it ensures the firm a perpetual monopoly for the production of the corresponding variety.

As stated above, we assume that the North is capital-abundant ( $K > K^*$ ). Due to the home market effect, this implies that this country also keeps the highest share of industry (Baldwin et al., 2003). The worldwide capital endowment is fixed (there is no economic growth). Thus, the worldwide number of varieties and firms is determined by the aggregate stock of capital:  $N = n + n^* = K + K^*$ . Capital is mobile between countries with no reallocation costs. Once the investment in capital has been made, each firm chooses where to locate its production and produces monopolistically the new variety. Unlike firms, households are immobile and, thus, their income is geographically fixed. That is to say, if the owner of a firm decides to locate production in the country where he or she does not reside, the capital rents are repatriated and spent in the owner's region, regardless of where the capital is employed. According to Martin and Ottaviano

(1999), this fixed demand avoids a cumulative agglomeration process as a result of capital movements that could lead to the full concentration of industry in one country. Thus, core-periphery equilibria with either  $n = 0$  or  $n^* = 0$  are excluded.

### *Natural resource sector*

As stated above, the South is endowed with a stock of the natural resource ( $S$ ), characterised as in Eliasson and Turnovsky (2004) or in Brander and Taylor (1997a, 1997b, 1998a, 1998b). This natural resource has specific characteristics: (i) it is renewable, (ii) it is open-access, (iii) it is used only as an input in the production of manufactured goods and (iv) its exploitation requires only labour. Therefore, our model is specifically suited to the particular case of forest areas because a natural resource with such characteristics is, for example, the wood from the forests of the South. The Amazon forest is the best representative case.

At any point in time, the evolution of the stock of the resource is given by

$$\dot{S} = G(S) - R,$$

where  $G(S)$  describes the natural growth of the resource and  $R$  is the amount harvested. We assume that the function  $G$  is concave and positive in the interval  $[0, \bar{S}]$ , where  $\bar{S}$  is the maximum amount that the stock can reach, given the physical and natural limitations (e.g., available space).  $G(S)$  is analogous to a production function, with the difference that the rate of accumulation of the stock is limited (see Brown (2000) for a wider discussion of  $G(S)$  and its properties). As usual, let us particularise  $G(S)$  with the logistic function:

$$G(S) = \gamma S \left( 1 - \frac{S}{\bar{S}} \right), \quad (4)$$

where  $\gamma > 0$  is the intrinsic growth rate of the resource (the natural growth rate). In the absence of harvesting ( $R = 0$ ),  $S$  converges to its maximum sustainable stock level,  $\bar{S}$ . This function has been widely used in the analysis of renewable resources, and it may be the simplest and most empirically plausible functional form of describing biological growth in a restricted environment.

The exploitation of the natural resource requires only labour and this is carried out by profit-maximising firms operating under conditions of free entry. We consider a standard harvesting function (Schaefer, 1957):

$$R = BSL_R, \quad (5)$$

where  $L_R$  is the amount of (Southern) labour used in the renewable resource sector and  $B$  is a positive productivity parameter. This technology implies that the labour requirement for harvesting one unit of the resource is  $1/BS$ , higher the lower the available stock of the resource.

### 3. Equilibrium

#### *Consumers*

Consumers maximise their welfare by choosing the amount consumed for every variety of manufactures as well as for the numerary good at every moment in time. In particular, Northern consumers maximise their utility in Eq. (1), where the manufactures index  $D_i$  is given by Eq. (2), subject to the budget constraint

$$E_t = \int_{i \in n} p_i D_{it} di + \int_{j \in n^*} \tau p_j^* D_{jt} dj + Y_t, \quad \forall t, \quad (6)$$

where  $E_t$  captures the expenditure in  $t$ . The solution of this problem can be divided in two stages. In the first one, the distribution of expenditure  $E$  over time is determined. The intertemporal optimisation of (1) subject to (6) implies an individual expenditure evolving over time depending on the difference between the interest rate and the intertemporal discount rate:  $\dot{E}_t/E_t = r_t - \rho$  (the dot over any variable indicates its derivative with respect to time). Since we do not consider any growth engine capable of generating sustained growth in this economy, in steady state the expenditure will remain constant and, thus,  $r_t = r = \rho$ . For the sake of clarity, we drop in what follows the subscript  $t$  when the variables are constant in time.

In the second stage, given the expenditure  $E$ , the optimal distribution of this amount between the different goods for any moment in time implies the following demand functions for each variety produced in the North ( $D_i$ ), in the South ( $D_j$ ), and for the numerary good:

$$D_i = \frac{\sigma - 1}{\beta\sigma} \cdot \frac{(\tau_R p_R)^{-\mu\sigma}}{n(\tau_R p_R)^{\mu(1-\sigma)} + n^* \delta p_R^{\mu(1-\sigma)}} \alpha E, \quad (7)$$

$$D_j = \frac{\sigma - 1}{\beta\sigma} \cdot \frac{\tau^{-\sigma} p_R^{-\mu\sigma}}{n(\tau_R p_R)^{\mu(1-\sigma)} + n^* \delta p_R^{\mu(1-\sigma)}} \alpha E, \quad (8)$$

$$Y = (1 - \alpha)E, \quad (9)$$

where  $p_R$  is the price of the resource and  $\delta = \tau^{1-\sigma}$  is a parameter between 0 and 1 that measures the openness of trade for manufactures:  $\delta = 1$  represents a situation in which transport costs do not exist ( $\tau = 1$ ), while if  $\delta = 0$  trade would be impossible because of the high transaction costs ( $\tau \rightarrow \infty$ ). According to Eqs. (7)–(9), a fraction  $1 - \alpha$  of expenditure from the North's consumers is devoted to the traditional good and the remaining fraction  $\alpha$  is shared between all varieties of manufactures, with a lower demand for the varieties produced in the South, whose price is higher due to the additional transport costs associated to the natural resource. The problem and the resulting demand functions of a consumer in the South are symmetrical to the expressions above.

### ***Manufactures market equilibrium***

The minimisation of costs of any firm producing the variety  $i$  in the North determines the demand for labour and the natural as:

$$D_{Li} = \beta(1 - \mu)(\tau_R p_R)^\mu x_i, \quad D_{Ri} = \beta\mu(\tau_R p_R)^{\mu-1} x_i, \quad (10)$$

respectively. The corresponding demands for Southern firm are similar except for the fact that they do not support the transport costs associated to the natural resource. Thus, other things being equal, the natural resource is more costly for Northern firms and, thus, they will use this input less intensively than the firms located in the South. Because of the symmetry among varieties, we drop in what follows the subindex  $i$  indicative of the different varieties where it is not necessary.

The equilibrium in the market of any variety requires that the supply satisfies worldwide demand, including the amount lost during transport when production and consumption take place in different countries. Thus, from the demands of Northern consumers in Eq. (7) and Eq. (8) and the equivalent demands of Southern consumers, the equilibrium condition in the market of any variety produced in the North becomes

$$x = \frac{\alpha L(\sigma - 1)}{\beta \sigma} (\tau_R p_R)^{-\mu \sigma} \left[ \frac{E}{n(\tau_R p_R)^{\mu(1-\sigma)} + n^* \delta p_R^{\mu(1-\sigma)}} + \frac{\delta E^*}{n \delta (\tau_R p_R)^{\mu(1-\sigma)} + n^* p_R^{\mu(1-\sigma)}} \right], \quad (11)$$

whereas for any variety produced in the South it is given by:

$$x^* = \frac{\alpha L(\sigma - 1)}{\beta \sigma} p_R^{-\mu \sigma} \left[ \frac{E^*}{n \delta (\tau_R p_R)^{\mu(1-\sigma)} + n^* p_R^{\mu(1-\sigma)}} + \frac{\delta E}{n(\tau_R p_R)^{\mu(1-\sigma)} + n^* \delta p_R^{\mu(1-\sigma)}} \right]. \quad (12)$$

These expressions show that the amount produced of each variety depends, among other variables, on the geographical distribution of the income (which depends on the geographical distribution of capital and labour) and on the price and transport cost of the natural resource, as part of the costs in the sector.

From the above results, the operating profits of the firms are also different depending on their location. For any firm in the North, the operating profit is:

$$\pi = px - \beta (\tau_R p_R)^\mu x = \frac{\beta}{\sigma - 1} (\tau_R p_R)^\mu x, \quad (13)$$

whereas for any firm in the South, it comes given by:

$$\pi^* = p^* x^* - \beta p_R^\mu x^* = \frac{\beta}{\sigma - 1} p_R^\mu x^*, \quad (14)$$

where  $x$  and  $x^*$  are the optimum production scales of a representative firm in the North and in the South, respectively.  $\pi$  and  $\pi^*$  capture the capital rents per unit of capital in the North and the South, respectively.

Apart from variable costs, manufacturing firms are also subject to the fixed cost associated to the unit of capital required to start their activity. The value of any unit of capital in the capital market  $v$  is given by the present value of the future flow of capital rents it can generate. The usual arbitrage condition on capital markets implies  $v + \pi = rv$ , where  $r$  is the interest rate paid by a safe asset whose market is characterised by a freedom of international movements ( $r = r^*$ ). In steady state, the value of a firm (i.e., of a unit of capital) must be constant; thus,  $v = \pi/r$ .

Capital moves freely between countries looking for the highest rents. A standard way of describing factor flows between countries is the following ad hoc “migration” equation (Baldwin et al., 2003, ch. 3):

$$\left(\frac{\dot{n}}{N}\right) = (\pi - \pi^*) \left(1 - \frac{n}{N}\right) \frac{n}{N}, \quad (15)$$

where  $n/N$  captures the proportion of manufacturing firms located in the North. This “migration” equation describes how firms move and the speed of the adjustment; with this specification, transition to equilibrium is not immediate, allowing us to differentiate between short and long run effects. As far as the capital rents in Eq. (13) and Eq. (14) are different, firms will tend to move to the country with the higher rents. This geographical reallocation would take place until the differences disappear. Thus, in the long run equilibrium,  $\left(\frac{\dot{n}}{N}\right) = 0$ ,  $\pi = \pi^*$  and  $v = v^*$ , which implies

$$x^* = \tau_R^\mu x. \quad (16)$$

Applying this condition to Eq. (11) and Eq. (12) allows us to obtain the long-run geographical distribution of manufacturing firms as a function of the geographical distribution of income:

$$\frac{n}{N} = \frac{1}{1 - \delta \tau_R^{\mu(1-\sigma)}} \cdot \frac{E}{E + E^*} - \frac{\delta}{\tau_R^{\mu(1-\sigma)} - \delta} \cdot \frac{E^*}{E + E^*}. \quad (17)$$

Northern individual income comes from labour (one unit supplied, paid at the wage rate  $w = 1$ ) and the interest on individual investment ( $vK/L$ ) and, thus,  $E = 1 + \rho vK/L$ . In steady state, the only difference in income between both countries is given by their different amounts of capital. Our assumption of a concentration of capital in the North implies a higher income in this country:  $E > E^*$ . In such a context, it can be shown from Eq. (17) that, for any value of the rest of parameters, manufacturing firms are also concentrated in the North ( $n > n^*$  or, equivalently,  $n/N > 1/2$ ).

Moreover, using Eq. (17) we can rewrite Eq. (11) and Eq. (12) as

$$x = \frac{\alpha L(\sigma - 1)}{\beta \sigma} \cdot \frac{E + E^*}{N} \cdot (\tau_R p_R)^{-\mu}, \quad \text{and} \quad x^* = \frac{\alpha L(\sigma - 1)}{\beta \sigma} \cdot \frac{E + E^*}{N} \cdot p_R^{-\mu}, \quad (18)$$

respectively. Carrying Eq. (18) to Eq. (13) and Eq. (14), and using the expression for the value of a firm  $v$ , we have  $E = 1 + \frac{2\alpha}{\sigma - \alpha} \cdot \frac{K}{N}$  and  $E^* = 1 + \frac{2\alpha}{\sigma - \alpha} \cdot \frac{K^*}{N}$ , with  $K/N$

and  $K^*/N$  denoting the share of capital owned by the North and the South, respectively ( $K + K^* = N$ ;  $K/N > 1/2$ ). Thus, from Eq. (17):

$$\frac{n}{N} = \frac{1}{1 - \delta \tau_R^{\mu(1-\sigma)}} \cdot \frac{\sigma + \alpha \left( 2 \frac{K}{N} - 1 \right)}{2\sigma} - \frac{\delta}{\tau_R^{\mu(1-\sigma)} - \delta} \cdot \frac{\sigma + \alpha \left( 2 \frac{K^*}{N} - 1 \right)}{2\sigma}. \quad (19)$$

This expression shows clearly the elements that incentivise the concentration of manufacturing firms in the North. First, the distribution of firms follows the distribution of capital, as noted above: the higher the Northern supremacy in the endowment of capital, the higher the geographical concentration of firms in this region. The reason is that a higher endowment of capital generates higher capital rents, and thus a larger domestic market, which attracts more firms willing to take advantage of increasing returns. This is what the literature identifies as the “home market effect”.

Second, as the literature of economic geography emphasises, a lower transport cost of manufactures works against the geographical homogenisation of the economic activity: the higher the freedom of trade in manufactures  $\delta$ , the lower the concentration of firms in the North. Finally, and this is the key point for our interests, it can be shown that the opposite role is played by the transport cost of the natural resource: a reduction in this cost lowers the advantage of locating in the South because of the presence of the natural resource and thus incentives the location of firms to the North, favouring industrial concentration. Thus, given that most firms are concentrated in the North, the home market effect (one of the so-called “second nature” causes in the literature) acts centripetally, favouring the agglomeration of economic activity, while the cost advantage offered by the natural resource to firms located in the South, (a “first nature” cause) acts centrifugally.

### ***Natural resource market equilibrium***

The extraction of the natural resource (at an amount  $R$ ) is carried out by profit-maximising firms operating under conditions of free entry (perfect competition). Therefore, from Eq. (5) the price of the resource good must equal its unit production cost<sup>3</sup>:

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<sup>3</sup> Note that the assumption of open access to the resource implies that the only explicit production cost is labour. Otherwise, another implicit cost should be considered to be associated with a reduction in the capacity of the reproduction of the resource, according to Hotelling’s rule. The resource would be

$$p_R = \frac{w}{BS} = \frac{1}{BS}. \quad (20)$$

The firms in the sector of the differentiated goods use the natural resource as an input in the production of their varieties. From Eq. (10), the demand of the natural resource of a representative firm of the North is  $\beta\mu(\tau_R p_R)^{\mu-1} x$ , whereas the demand of a Southern firm is  $\beta\mu p_R^{\mu-1} x^*$ . By aggregating demand of the firms located in the North (taking into account the transport cost they bear) and of those located in the South, the worldwide demand for the natural resource amounts to

$$D_R = n\tau_R D_{Ri} + n^* D_{Ri^*} = \beta\mu p_R^{\mu-1} (\tau_R^{\mu-1} n x + n^* x^*), \quad (21)$$

which, using the expressions in Eq. (18) can be written as  $D_R = \mu \frac{\alpha(\sigma-1)}{\sigma} L(E + E^*) p_R^{-1}$ . Thus, taking into account Eq. (20) and the values of  $E$  and  $E^*$ , the natural resource market equilibrium implies:

$$R = 2\mu \frac{\alpha(\sigma-1)}{\sigma-\alpha} BSL. \quad (22)$$

Note that, since the price of the resource decreases with the size of the stock  $S$ , the opposite applies to the amount  $R$  harvested in equilibrium. The steady state in this sector is reached when the amount extracted equals the capacity for the reproduction of the natural resource:  $\dot{S} = G(S) - R = 0$ . A trivial solution is  $S = R = 0$ . The other solution is given by:

$$S = \bar{S} \left[ 1 - 2\mu \frac{\alpha(\sigma-1)}{\gamma(\sigma-\alpha)} BL \right]. \quad (23)$$

In the long run, the stock of the resource tends to be higher the higher its maximum sustainable value  $\bar{S}$  and the higher its natural growth rate  $\gamma$ . By contrast, a higher population  $L$ , a better efficiency in the extraction process  $B$  or a higher intensity in the use of the natural resource in the production of manufactures  $\mu$  work in the opposite direction, leading the stock of the natural resource to fall in the long run.

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exploited only by firms with property rights in a situation of imperfect competition, making the final price greater than the unit cost, and generating additional income for the owners of the extractive firms.

Note that neither the transport costs nor the geographical distribution of manufacturing firms affects the sustainable stock in the long run equilibrium.

Figure 2 shows how convergence is produced to such a steady state level. The figure illustrates a situation in which at the initial stock  $S_0$  the amount harvested  $R$  exceeds the natural growth of the resource  $G(S_0)$ , which leads to a progressive reduction in the stock until it eventually reaches the steady state level  $\tilde{S}$ . By substituting Eq. (23) in Eq. (22), in such a long run situation, the quantity of the resource used by firms is constant and amounts to:

$$R = 2\mu \frac{\alpha(\sigma - 1)}{\sigma - \alpha} \bar{B} \bar{S} L \left[ 1 - 2\mu \frac{\alpha(\sigma - 1)}{\gamma(\sigma - \alpha)} \bar{B} L \right]. \quad (24)$$

As shown by Brander and Taylor (1997a), a positive (and globally stable) steady state solution exists if and only if the term between brackets is positive. Graphically, this condition requires that the slope of the harvesting function  $R$  is lower than the slope of  $G(S)$  in the origin, thus ensuring that they cut off at some point for a positive value of  $S$ . Increases in the exploitation of the resource (Eq. 5) reduce the stock in the long run equilibrium<sup>4</sup>.

### ***Labour market equilibrium***

Finally, we must take into account the labour market. Labour demand comes from three groups of firms: those producing manufactures, those producing the traditional good and those that harvest the resource in the South. According to Eq. (10), labour demand in the manufactures sector is given by  $\beta(1 - \mu)(\tau_R p_R)^\mu x$  for any of the  $n$  firms operating in the North and by  $\beta(1 - \mu)p_R^\mu x^*$  for any of the  $n^*$  firms located in the South. After substituting Eq. (18) and aggregating for all firms, the total demand in this

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<sup>4</sup> However, the effect on the long-run harvest depends on whether the equilibrium lies on the increasing or the decreasing part of the curve  $G(S)$ . The more intuitive result corresponds to the latter: a higher exploitation of the resource leads in the long run to a higher extraction and a lower stock. On the increasing part of the curve, the final effect is a shortcut in the harvest because the stock decreases very quickly; even more, a higher exploitation of the resource can easily lead to its extinction (small movements of the function  $R$  upwards can generate a unique steady state with  $R = S = 0$ ).

sector amounts to  $(1-\mu)\frac{\alpha(\sigma-1)}{\sigma}L(E+E^*)$ . In the sector of the traditional good, the labour demand is  $(1-\alpha)LE$  in the North and  $(1-\alpha)LE^*$  in the South – see Eq. (9). Finally, from Eq. (5), the labour demand in the resource sector is given by  $L_R = R/BS$ , which, taking into account Eq. (22), implies  $L_R = \mu\frac{\alpha(\sigma-1)}{\sigma}L(E+E^*)$ . Thus, the worldwide aggregate demand for labour is  $\frac{\sigma-\alpha}{\sigma}L(E+E^*)$ . With an aggregate supply of  $2L$ , the equilibrium in the labour market implies  $E+E^* = \frac{2\sigma}{\sigma-\alpha}$ .

#### 4. Effects of the trade liberalisation of natural resource

Having solved the equilibrium of the model, we now focus on the main purpose of this paper, namely the identification of the effects of the progressive reduction in the transport costs on the distribution of economic activity and, more specifically, on the performance of natural resource availability, both in the short run and in the long run.

A reduction in the natural resource trade cost has no immediate effect on the South (the firms located in this country do not bear such cost), but implies a reduction in the cost associated with the use of the resource by firms located in the North. This changes the worldwide demand for the resource, and thus its harvest and its price, as well as the production and the price of each variety of the manufactures – initially for the firms in the North, but also for the firms in the South after readjustments in worldwide demand. The associated change in profits would generate incentives for a movement from one country to the other; according to our “migration” equation (Eq. 15), such movement would take place slowly. We identify the short run effects with the changes that take place before the firms can undertake the changes in location, that is to say, for a given distribution of manufacturing firms – the one described in the preceding section. Having identified the short run changes, a transition process starts in which some firms move their location and readjust their decisions of production and use of inputs. As we will see, the incentives to move mitigate along the transition and eventually a new steady state is reached in which the geographical distribution of the firms is again stable. The changes experienced in this last situation are what we identify as the long run effects.

For the sake of simplicity in presentation, the equilibrium described in the preceding section focused mainly in the long run performance of the economy. The long run equilibrium is easier to characterise for two reasons. The first is that the behaviour of the variables is regular. Indeed, given that no economic growth engines are included, they become constant. This is the case, among others, for the distribution of labour, the scale of the manufacturing firms, the value of these firms and, related to the natural resource sector, its price, the amount harvested and the stock available. The second reason is that the process of the reallocation of firms, which we assume is not immediate, has been completed in the long run, so that an additional condition applies: in steady state, the benefits for firms are equal independently of their location. We depart from such equilibrium to analyse the consequences of trade liberalisation.

### *Short run effects*

Five expressions in the above section are obtained without imposing any of the steady state properties: in the manufactures sector, Eq. (11) and Eq. (12) indicate the scale of production of the different varieties that clears the markets, whereas Eq. (13) and Eq. (14) measure the operating profits of the firms that produce them; and in the natural resource sector, Eq. (21) captures the demand of the resource from the manufactures sector. We will use these expressions to analyse the short run effects, taken the geographical distributions of the firms  $(n, n^*)$  as given.

The most immediate effect is that a decrease in the cost of trading the natural resource ( $d\tau_R < 0$ ) leads to a reduction in the costs of manufacturing firms located in the North, which have to import the resource. This fall in production costs translates to lower market prices for Northern varieties. No change in costs and prices takes place in the case of Southern varieties. Thus, since the varieties produced in the North become more competitive, part of the expenditure in manufactures deviates from Southern varieties towards Northern varieties. As a consequence, the production of manufacturing firms located in the North (Eq. 11) increases, whereas that of firms in the South (Eq. 12) decreases.<sup>5</sup>

This demand deviation increases the operating profits of the firms located in the North. Since the elasticity of the demand for any variety is higher than one by assumption ( $\sigma > 1$ ), although the price charged is lower, the demand increases more

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<sup>5</sup> Analytical effects are shown in the appendix.

than proportionally, thus increasing profits in Eq. (13). By contrast, the reduction in demand for varieties produced in the South leads to lower profits for Southern firms (Eq. 14).

Since the natural resource is an input in the manufacturing sector, the manufactures demand deviation after the liberalisation of trade also has an impact on the natural resource performance. Worldwide demand is obtained in Eq. (21). On the part of Southern firms, the fall in the demand for their varieties ( $dx^*/d\tau_R > 0$ ) leads to a parallel fall in their demand of inputs, particularly of the natural resource. The last addend in Eq. (21) captures this effect. On the part of the Northern firms, two effects apply: first, the higher demand for their varieties ( $dx/d\tau_R < 0$ ) requires an increased amount of the natural resource for their production. Second, since the amount lost in travel is lower, the demand in origin also lowers. The first term between brackets in Eq. (21) includes these two opposite effects. After some (cumbersome) algebra, it can be shown that the first effect dominates (again, the high elasticity of demand for manufactures implies that the reaction in the amount used of the resource is higher than the fall in its cost), and therefore the demand for the natural resource from Northern firms increases.

This means that the deviation in consumers demand for manufactures towards Northern varieties is accompanied by a parallel deviation of the demand for the natural resource: it increases in firms located in the North and diminishes in the case of the South. Since the manufactures industry is concentrated in the North, we can conclude that, in the short run, worldwide demand for the natural resource increases. From Eq. (21),

$$\frac{dD_R}{d\tau_R} = -\beta\mu^2(\sigma-1)(1-\delta)(\tau_R p_R)^{\mu-1} n x < 0.$$

Note that such an impact on worldwide demand for the resource is higher the higher is the concentration of the manufactures in the North (higher  $n$ ).

This higher demand implies a more intensive harvest of the natural resource  $R$ , which lowers the stock available. In turn, since the cost of harvesting reduces as the stock expands, the reduction in stock increases the harvest cost and the price of the resource  $p_R$ . This latter effect slows down the initial increase in demand.

In summary, the liberalisation in natural resource trade leads in the short run to a higher exploitation, a higher price and a reduction in the stock available of the natural resource. This theoretical result reproduces the empirical evidence observed in the case of forest areas, mentioned above in the introduction and summarised by Robalino and Herrera (2009).

### *Transition*

Changes in the short run move the economy away from the initial steady state equilibrium and initiate a succession of further changes for some time until eventually reaching a new steady state. We highlight the main issues.

First, the increase in the harvest of the resource over its natural capacity of expansion makes the stock of the resource fall. In the absence of more forces, this diminishes the demand pressure (because of the increase in its price associated with a higher cost of harvesting) and increases the natural growth of the resource (because of lower congestion)<sup>6</sup>. As a result, these forces determine a progressive reduction of the stock, although at a slower rate over time. However, more elements are at work.

The changes in the manufacturing sector have generated a short run edge between the profits of firms located in the North and those in the South, with higher profits in the first group ( $\pi - \pi^* > 0$ ). This is a clear incentive for Southern firms to move their plants to the North, because a change in the location of firms depends on the differences in profits (Eq. 15). Therefore, the transition is characterised by a movement of firms from the South to the North, which strengthens the concentration of manufactures in the North.

On one hand, this movement of firms mitigates progressively the differences in profits, converging to a new steady state. On the other, it also has consequences on the evolution of the stock of the natural resource. As noted before, from the individual firm demands for the natural resource (Eq. 10) it is immediate that the firms located in the South use more intensively the resource in the production of manufactures compared with those located in the North (obviously, the opposite applies with labour). With this lower use of the resource in the North, the movement of some firms to this country implies lowering demand at a worldwide level.

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<sup>6</sup> This is the case in the decreasing part of  $G(S)$ . In the increasing part, the natural growth of the resource is reduced but to a smaller extent compared with demand, so that the same conclusions apply.

This reduction in demand for the resource (because of the reallocation of firms) mitigates the short run increase in demand (because of the fall in transport cost). This means that, over the transition, the short run effect on demand reverses, with a parallel reversal in the evolution of the stock of the resource.

In short, the initial deterioration of the stock will recover over time, giving rise to what in the case of forests has been identified as “the forest transition”. As stated in the introduction, many explanations can be found behind this phenomenon. The economic geography contribution developed in this paper lies on the different intensity in the use of the resource depending on the distance of firms that use the wood to the forest. Firms close to the resource use it more intensively. With the South being the main wood provider, the progressive concentration of industry in the North as a result of the liberalisation of trade reduces pressure on forests and contributes to a reversal of the initial negative effects.

### ***Long run effects***

Our specification allows us to go further. Although, for the matter of simplicity, we have not solved algebraically the transition, we can easily determine the changes in the new steady state. Two of these are worth highlighting. First, as a result of transition dynamics, it is clear that in the long run the industry becomes more concentrated in the North ( $n$  increases in the new steady state). This effect can be easily obtained through the expression in Eq. (19): a reduction in  $\tau_R$  leads to an increase in  $n/N$ .

Second, the short run negative impact on the stock of the natural resource not only mitigates over time, but eventually disappears. The stock in the long run is given by Eq. (23), which is not affected by transport costs. Thus, in the long run the stock of the resource recovers to its initial size, reflecting that the initial decrease vanishes completely during the transition.

## **5. Conclusions**

Recent empirical studies identify a tendency of some forest areas to recover after several periods of deforestation. The FTT provides an explanation for this behaviour based on factors such as relative prices, land use, migrations, transport costs or industrial concentration. However, the driving force behind all these factors is trade liberalisation.

In general, a reduction in transport costs changes the geographical organisation of production and, in particular, the intensity of the exploitation of natural resources in specific areas. When such exploitation is reduced in one area, it allows for a recuperation of the stock of the resource at a local level. However, from a global point of view, the forces behind this process shift the pressure on natural resources from some areas to others. Thus, although the former experience a forest transition and a recovering of the stock of the resource, at a global level the exploitation could be the same or even larger.

In this paper, we developed a new theoretical model to explain the possibility of a forest transition not in a local area, but at a worldwide level, in a trade liberalisation scenario. Our model has economic geography foundations: transport costs affect the distribution of firms between countries. We also introduce a renewable natural resource used as an input by manufacturing firms, which is concentrated in a specific area, namely developing countries. The short-term results are in line with the empirical evidence in the literature: a decrease in transport cost has a negative effect on the stock of the natural resource.

However, we go further by considering the industrial reorganisation between countries because of this change in transport cost. Concretely, trade liberalisation goes hand in hand with a progressive concentration of industry in developed countries. This industrial reallocation lowers the pressure on the natural resource and reverses the short run effects. As a result, in the long-term exploitation is reduced and the stock of the resource recovers. In our specific framework, the short run depletion of the resource even vanishes completely. This allows us to identify this process as a forest transition at a worldwide scale.

### **Appendix: Short run effects**

Eq. (11) and Eq. (12) indicate the scale of production of the different varieties that clears the markets, including transport costs. In the short run, keeping the distribution of firms constant, the effect of a decrease in the cost of trading the natural resource ( $d\tau_r < 0$ ) on the production of a representative firm  $i$  located in the North is

$$\frac{dx_i}{d\tau_R} = -\mu\sigma \cdot \frac{x_i}{\tau_R} + \frac{\alpha L(\sigma-1)}{N\beta\sigma} (\tau_R p_R)^{-\sigma\mu} \cdot \frac{n}{N} p_R^{\mu(1-\sigma)} \mu(\sigma-1) \tau_R^{\mu(1-\sigma)-1} \cdot \left[ \frac{E}{\left(\frac{n}{N} (\tau_R p_R)^{\mu(1-\sigma)} + \left(1 - \frac{n}{N}\right) \delta p_R^{\mu(1-\sigma)}\right)^2} + \frac{\delta^2 E^*}{\left(\frac{n}{N} \delta (\tau_R p_R)^{\mu(1-\sigma)} + \left(1 - \frac{n}{N}\right) p_R^{\mu(1-\sigma)}\right)^2} \right]$$

The first term is negative, and the second positive. Let us make  $\varepsilon = -\frac{dx_i}{d\tau_R} \cdot \frac{\tau_R}{x_i}$ . Then,

the expression can be rewritten as

$$\varepsilon = \mu \left[ \sigma - (\sigma-1) \frac{\tau_R}{x_i} \cdot \frac{\alpha L(\sigma-1)}{N\beta\sigma} \left((\tau_R p_R)^\mu\right)^{-\sigma} \cdot \frac{n}{N} \left(p_R^\mu\right)^{1-\sigma} \tau_R^{\mu(1-\sigma)-1} \cdot \left[ \frac{E}{\left(\frac{n}{N} (\tau_R p_R)^{\mu(1-\sigma)} + \left(1 - \frac{n}{N}\right) \delta p_R^{\mu(1-\sigma)}\right)^2} + \frac{\delta^2 E^*}{\left(\frac{n}{N} \delta (\tau_R p_R)^{\mu(1-\sigma)} + \left(1 - \frac{n}{N}\right) p_R^{\mu(1-\sigma)}\right)^2} \right] \right]$$

Substituting  $x_i$  from Eq. (11) and making  $\varphi = \frac{n}{N} (\tau_R p_R)^{\mu(1-\sigma)}$  and  $\psi = \left(1 - \frac{n}{N}\right) p_R^{\mu(1-\sigma)}$

we obtain

$$\varepsilon = \mu \left[ \sigma - (\sigma-1) \cdot \varphi \cdot \left[ \frac{\frac{E}{E+E^*} (\delta\varphi + \psi)^2 + \delta^2 \left(1 - \frac{E}{E+E^*}\right) (\varphi + \delta\psi)^2}{\frac{E}{E+E^*} (\varphi + \delta\psi) (\delta\varphi + \psi)^2 + \delta \left(1 - \frac{E}{E+E^*}\right) (\varphi + \delta\psi)^2 (\delta\varphi + \psi)} \right] \right]$$

It can be proven that the term in brackets is positive for any  $\frac{1}{2} < \frac{E}{E+E^*} \leq 1$ . Therefore,

$$\varepsilon = -\frac{dx_i}{d\tau_R} \cdot \frac{\tau_R}{x_i} > 0 \text{ and } \frac{dx_i}{d\tau_R} < 0.$$

For a representative firm  $j$  located in the South, the effect of a change in the trade cost of the natural resource is

$$\frac{dx_j^*}{d\tau_R} = \frac{\alpha L(\sigma - 1)}{N\beta\sigma} P_R^{-\mu\sigma} \frac{n}{N} \delta p_R^{\mu(1-\sigma)} \mu(\sigma - 1) \tau_R^{\mu(1-\sigma)-1} \cdot \left[ \frac{E^*}{\left(\frac{n}{N} \delta (\tau_R P_R)^{\mu(1-\sigma)} + \left(1 - \frac{n}{N}\right) P_R^{\mu(1-\sigma)}\right)^2} + \frac{E}{\left(\frac{n}{N} (\tau_R P_R)^{\mu(1-\sigma)} + \left(1 - \frac{n}{N}\right) \delta p_R^{\mu(1-\sigma)}\right)^2} \right] > 0$$

Finally, from the worldwide demand for the natural resource we can derive the effect of a change in the trade cost of the natural resource on the stock of the natural resource. From Eq. (21), it follows that

$$dD_R = \beta\mu p_R^{\mu-1} (n x_i \mu \tau_R^{\mu-1} d\tau_R + \tau_R^\mu n dx_i + n^* dx_j^*).$$

Applying the previously obtained expressions for  $dx_i$  and  $dx_j^*$ , replacing  $x_i$  from Eq. (11) and grouping terms we can obtain the expression shown in the main text

$$\frac{dD_R}{d\tau_R} = -\beta\mu^2(\sigma - 1)(1 - \delta)(\tau_R P_R)^{\mu-1} n x < 0.$$

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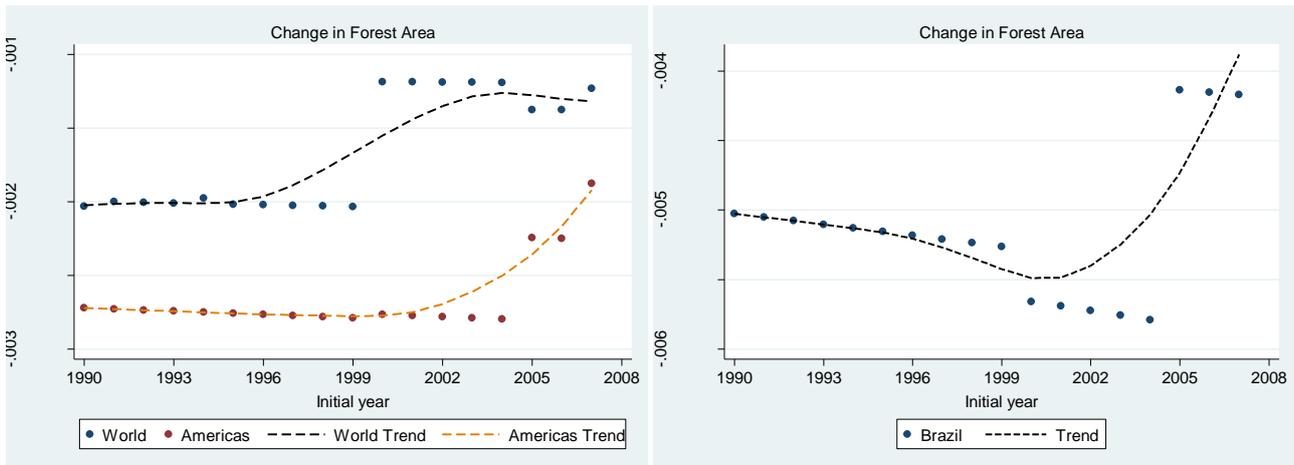
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**Figure 1. Change in forest area (annual rates of change), 1990–2008**



*Source:* FAOSTAT. The Global Forest Resource Assessment (2010) is the main source of forest area data in FAOSTAT. Data were provided by countries for the years 1990, 2000, 2005 and 2010. Data on intermediate years were estimated for FAO using linear interpolation and tabulation.

*Note:* Trend curves fitted by LOcally WEighted Scatter plot Smoothing (LOWESS).

**Figure 2. Dynamics of the resource**

