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Abstract: In this paper, we develop a new theoretical model that explains the forest transition not at a local, 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. The results reproduce forest transition behaviour but at a global scale: a decrease in transport costs has a negative effect on the worldwide stock of the natural resource in the short-term, but in the long-term this initial effect is reversed as a consequence of industrial reorganisation between countries because of the change in transport costs.

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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 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. 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.[1]

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 the liberalisation of international trade) as one of the most important causes of the change in this trend, as a consequence of the shift in the organisation of economic activity. 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 the effect on stock can be reversed because the change in transport costs induces a shift in the organisation of economic activity. Furthermore, this shift has multiple dimensions, related to 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 populations tend to be more dispersed), favouring the growth of the forest area (Carr, 2009).

[1] The argument can also be formulated in terms of Environmental Kuznets Curves, see Pfaff and Walker (2010).

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 shortcoming, as exposed by Rudel et al. (2005) and Pfaff and Walker (2010). To find a reversal of the trend the spatial scale is crucial. Thus, if we go back to the reasons explained 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. 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 of forest transition is only local.

From this point of view, there are two sides to forest transition, namely the different effects on developed and on developing countries. In other words, the effect is different depending on which countries concentrate industrial activity and which countries have an abundance of natural resources. The forest area increases in the former, while it decreases in the latter (Brander and Taylor, 1997a). And here comes the question: is a global forest transition also possible? Although the FTT seems to suggest that the pressure on natural resources simply moves from some countries to others, is it possible that these changes also influence the aggregate level of this pressure?

Moreover, is there any reason to expect that this aggregate impact would allow the worldwide forest area to recover?

Before other considerations, we acknowledge that previous arguments that support local forest transitions can hardly be extended to a global perspective. However, we can provide some additional arguments supporting a possible global forest transition. To this end, the analytical models of the New Economic Geography can be useful as they 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 Chapter 3 in Baldwin et al., 2003), which is also known as the footloose capital model. In this paper, we extend this analysis to consider two areas (North and South) with different natural endowments in order to analyse the effects of trade liberalisation not only on industrial location and on the concentration of economic activity between different countries, but also on the growth of their stocks of natural resources. Our model is able to reproduce the previously explained mechanisms. Thus, a reduction in transport costs has a negative effect on stock in the short-term, but in the long-term this initial effect is reversed as a consequence of the industrial reorganisation between countries because of the change in transport costs.

Regarding the endowments of natural resources, we normalise one of the country's endowments to zero in order to consider a completely asymmetric scenario. Thus, the natural resource is located only in one of the two countries, which we call South (strictly speaking, what we assume to be concentrated in the South is the exploitation of the resource; the North may have natural resources but they are not exploited for economic, environmental or other reasons). There are two reasons for this configuration. On one hand, it is an assumption that simplifies the model, and the results are qualitatively robust as long as we keep the relative abundance of natural resources in this area. 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 should be the worst case for the possibility of a global forest transition. Therefore, if we obtain arguments supporting a global forest transition even in such an extreme scenario, the same reasons may be true in a framework in which the natural resource is also exploited in the North.

In 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 may 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 changes in industrial location driven by trade liberalisation finally result in a drop in global demand for the resource that will, in the end, allow for the recovery of the initial level of forest area in the country with an abundance of the resource.

The remainder of the paper is structured as follows. Section 2 presents the basic characteristics of the theoretical model. Section 3 explains the 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 sector with a dynamic behaviour, namely the one related to the harvest of the natural resource.

We consider two countries, North and South, which trade with each other. In a broad sense, we can identify the North as the industrialised country and the South as the natural resources owner. There are two key differences between them that determine this characterisation. First, the natural resource is only available in the South (we normalise the North’s endowment to zero). This assumption carries 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. As we show, this is equivalent to considering that the initial level of capital in the North exceeds that in the South and implies that the North is 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 representative households playing the part of consumers and workers. There are L households, both in the North and in the South. 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:

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

with $0 < \alpha < 1$. ρ denotes the intertemporal discount rate, Y is a traditional homogeneous good (which we consider as the numerary 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:

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

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.

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[2]. 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:

$$x_i = L_i^{1-\mu} R_i^{\mu}, \tag{3}$$

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

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 initially capital-abundant ($K > K^*$), so that it has the highest share of industry. 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, and there are no relocation costs. Once the investment in capital has been made, each firm chooses where to locate its production and produces the new variety in a situation of monopoly. Unlike firms, households are immobile and, thus, their incomes are geographically fixed, although firms can move. In other words, if a firm owner decides to locate production in the

[2] The restriction on parameters for the constant returns to scale sector that exists in both countries is the same as in Martin and Ottaviano's model, see Appendix A in Martin and Ottaviano (1999).

country where he or she does not reside, he or she repatriates the profits and that income is spent in the owner's region regardless of where the capital is employed.

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 $[0, \overline{S}]$, where $\overline{S}$ 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:

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

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, $\overline{S}$. 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):

$$R = BSL_R , \tag{5}$$

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.

Trade

International trade between the two countries is costly, which we capture using iceberg-type transport costs (Samuelson, 1954): τ and τ_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 $\tau_R \le \tau$: it is less costly (or, at best, equal) to transport natural resource compared with manufactures[3]. For simplicity, we adopt the usual assumption that the traditional good is not subject to transaction costs.

3. Equilibrium

Consumers

Consumers maximise their welfare by choosing the amount consumed for every variety of manufactures as well as for the numerary good. For Northern consumers, given a current expenditure E, their problem consists of maximising the utility in Eq. (1), where the manufactures index D is given by Eq. (2), subject to the budget constraint

[3] 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.

$$\int_{i\in n} p_i D_i di + \int_{j\in n^*} \tau p_j^* D_j dj + Y = E \,. \tag{6}$$

The solution of this problem implies the following demand functions for each variety produced in the North (D_i), in the South (D_j), and for the numerary good:

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

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

$$Y = (1-\alpha)E \,, \tag{9}$$

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, while if $\delta = 0$ trade would be impossible because of the high transaction costs. According to Eqs. (7)–(9), a fraction $1-\alpha$ of expenditure from the North's consumers is devoted to the intermediate good and the remaining fraction α is shared between all varieties of manufactures, with a lower demand for the varieties produced in the South, which, because of transport costs, have a higher price. The problem and the resulting demand functions of a consumer in the South are symmetrical to the expressions above.

The intertemporal optimisation of consumers implies an individual expenditure evolving over time depending on the difference between the interest rate and the intertemporal discount rate: $\dot{E}/E = r - \rho$. 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, $r = \rho$.

Manufactures market equilibrium

The use of the resource available only in the South makes manufacturing costs different depending on whether the firms are located in the North or in the South. From the technology of the production of manufactures (3), the variable cost of producing one 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). The fixed costs associated with the acquisition of the unit of capital should be added to calculate the total costs of the firm. 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 minimisation of costs determines the demand for labour and the natural resource of each firm i located in the North as:

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

respectively. The corresponding demands for Southern firm are parallel except for the fact that they do not include transport costs. Thus, other things being equal, the natural resource is more costly for Northern firms and thus they will use this input less intensively than would 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

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

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

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

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.

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: $p>p^*$.

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:

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

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

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

where x and x^* are the optimum production scales of a representative firm in the North and in the South, respectively.

Apart from variable costs, manufacturing firms are also subject to the fixed cost of the unit of capital required to start their activity. The value of any firm v in the capital market is given by the present value of its future flow of profits. The usual arbitrage condition on capital markets implies $\dot{v}+\pi=rv$, where π denotes operating profit and 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 must be constant; thus, $v=\pi/r$.

Capital freely moves looking for the highest nominal reward. A standard way of describing factor flows between countries is the following ad hoc "migration" equation (Chapter 3 in Baldwin et al., 2003):

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

where n/N represents the proportion of manufacturing firms located in the North. This "migration" equation represents 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, and overreaction situations are not allowed. As far as the profits in Eq. (13) and Eq. (14) are different, firms will tend to move to the country with higher profits. This geographical reallocation would take place until the differences disappear, then $\left(\dfrac{\dot{n}}{N}\right) = 0$. Thus, in the long run equilibrium, $\pi = \pi^*$ and $v = v^*$, which implies

$$x^* = \tau_R^{\mu} x . \tag{16}$$

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:

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

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, $E = 1 + \rho v K/L$. 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

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

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

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

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 means higher capital rents, and a higher income implies a larger domestic market, which attracts more firms wanting 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 δ, 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 incentivises 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 (of 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[4]:

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

[4] 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 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.

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 the firms in the North (taking into account the transport cost they bear) and those in the South, the worldwide demand for the resource amounts to

$$D_R = \beta\mu p_R^{\mu-1}\left(\tau_R^{\mu-1}nx + n^*x^*\right), \tag{21}$$

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

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

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:

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

In the long run, the stock of the resource tends to be higher the higher its maximum sustainable value $\overline{S}$ and the higher its natural growth rate γ. By contrast, a higher worldwide 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 μ work in the opposite direction, leading the stock of the natural resource to fall in the long run. 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:

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

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[5].

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 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

[5] 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 $R = S = 0$).

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.

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 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),

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

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)[6]. 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 $\left(\pi - \pi^* > 0\right)$. 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.

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

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[6] 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.

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 τ_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.

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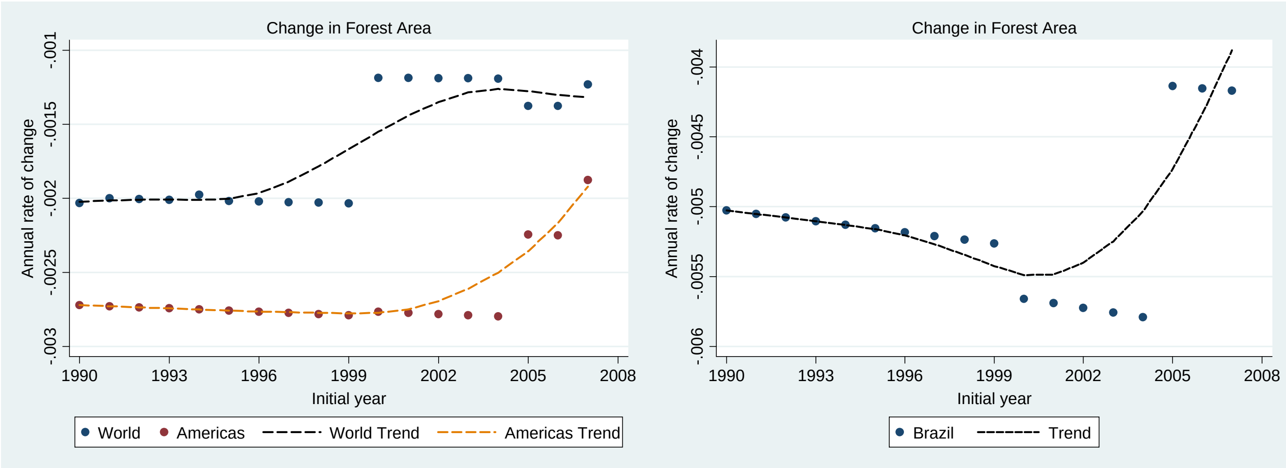
Figure 1. Change in forest area (annual rates of change), 1990–2008



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