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Natural Resources, Economic Growth and Geography

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Summary

In this paper we discuss the relationship between economic growth and natural resources at a global level, taking into account geography. With this aim, our model integrates elements of the theories of endogenous growth, natural resources and new economic geography. We find that an increase in the world growth rate can lead to a higher depletion of the natural resources following an increase in the world demand due to expansion in population. However, the consideration of geography and growth mechanisms make the relationship between growth and natural resources more complex, and can even lead to the opposite conclusion when the forces behind growth are different from world demand. Indeed, either a reduction in transport costs or an increase in R&D productivity appears to be able to generate a faster growth compatible with a lower depletion of natural resources.

Keywords: Industrial Location, Endogenous Growth, Renewable Resource, Geography

JEL Classification: F43, O30, Q20, R12

This paper is a revised version of our IEB Working Paper 2010/39. Earlier versions of this paper were presented at the 14th International Conference on Macroeconomic Analysis and International Finance (Crete, 2010), at the Fourth World Congress of Environmental and Resource Economists (Montreal, 2010), at the I Workshop on Urban Economics (Barcelona, 2010), at the 26th Annual Congress of the European Economic Association (Oslo, 2011), at the XVI Applied Economic Meeting (Granada, 2013), and at the Sixth World Congress of Environmental and Resource Economists (Gothenburg, 2018), with all the comments made by participants being highly appreciated. Financial support was provided by the Spanish Ministerio de Economía y Competitividad (ECO2017-82246-P and ECO2016-75941-R projects), the DGA (ADETRE research group) and FEDER.

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Natural resources, economic growth and geography

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Abstract: In this paper we discuss the relationship between economic growth and natural resources at a global level, taking into account geography. With this aim, our model integrates elements of the theories of endogenous growth, natural resources and new economic geography. We find that an increase in the world growth rate can lead to a higher depletion of the natural resources following an increase in the world demand due to expansion in population. However, the consideration of geography and growth mechanisms make the relationship between growth and natural resources more complex, and can even lead to the opposite conclusion when the forces behind growth are different from world demand. Indeed, either a reduction in transport costs or an increase in R&D productivity appears to be able to generate a faster growth compatible with a lower depletion of natural resources.

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1. Introduction

There are many factors influencing the distribution of economic activity. In the economic literature, locational fundamentals are one of the most important factors driving the geographic concentration of industrial activities (besides increasing returns to scale). Locational fundamentals are considered to be geographical factors linked to the physical landscape, such as temperature, rainfall, access to the sea, or factor endowments of natural resources. Among all of these natural characteristics, natural resources are especially important, because they can be used as inputs in the production of manufactured goods. From a physical geography perspective, mineral and other natural resources are clearly concentrated in certain areas, and several empirical studies find a significant influence of these natural resources on the development of some particular regions.

Combes et al. (2008) highlight that Kim (1995) may be viewed as a precursor in this empirical literature. Kim (1995) studied the relationship between the spatial concentration of an industry and plant size (the average size of firms in a specific sector at a given date) and raw-material intensity (the share of raw materials used in this sector) in the late 19th and early 20th centuries in the United States (US), finding that regional specialization was positively related to both variables. His interpretation of this result was that the manufacturing belt was based on the rise of large-scale production methods that were intensive in the use of raw materials and energy sources that were relatively immobile. In a subsequent work, Kim (1999) concluded that factor endowments were the fundamental explanation for the geographic distribution of US manufacturing from 1880 through 1987. Kim's results indicate that, once natural factor endowments had been taken into account, there was little left to be explained[1].

Nevertheless, although locational fundamentals may have played a crucial role in early settlements, one would expect that their influence decreases over time. Klein and Crafts (2012) find that natural advantage played a role in industrial location decisions in the US in the late 19th century, but its importance then faded away. However, other empirical studies demonstrate that the important influence of natural advantages in determining agglomeration remains. For the case of the US, Ellison and Glaeser (1999) state that natural advantages can explain about 20% of the observed geographic concentration.

[1] Kim's methodology has been criticized, see Combes et al. (2008) and Klein and Crafts (2012).

Although the temporary or permanent effect of natural endowments on industrial concentration may be debatable, many historical examples highlight how these natural advantages shape the distribution of economic activity. For instance, nearby deposits of coal, iron ore and limestone as well as the extensive network of natural waterways and deep water sea and river ports contributed to the development of the US manufacturing belt in the Upper Midwest and North-east regions (Berry and Kasarda, 1977). Fernihough and O'Rourke (2014) also find that coal had a strong influence on city population; according to their estimates coal explains at least 60% of the growth in European city populations from 1750 to 1900.

However, theoretical models are usually based on the assumption that the space is homogenous (one of the exceptions is Picard and Zeng, 2010), excluding the role played by the endowments of natural resources. In this paper, an endogenous growth model with two countries is developed to analyse the influence of the presence of natural resources on the concentration of economic activity and growth. To do this, we build a model in which firms can choose to locate in one of two countries which trade with each other, which we call North and South. This model integrates characteristics of the New Economic Geography, the theory of endogenous growth and the economy of natural resources.

Our model is closely related to the model by Martin and Ottaviano (1999), which combines a model of endogenous growth similar to that of Romer (1990), and Grossman and Helpman (1991), with a geographical framework like that of Helpman and Krugman (1985), and Krugman (1991). Economic growth is supported by an endogenous framework with national spillovers in innovation, causing research activities to take place in a single country, and thus, the greater the industrial concentration in that country, the higher the economic growth rate.

To this model, we add an open access renewable natural resource used by firms as a productive input. This introduces an additional element that conditions firms' decisions about whether to locate in the North or in the South, besides the traditional home market effect and the existence of trade costs. The relative importance of these three forces determines a non-symmetrical location of firms. The industrial geography here relates to the natural resource in two ways. First, the natural resource is located in only one of the two countries, namely, the South (we normalize the stock of the resource in the North to zero). Second, the international trade of the natural resource between countries is subject to a transport cost.

There are other theoretical models which study how the presence of natural resources affects international trade, focusing on factors such as comparative advantages and relative prices (Brander and Taylor, 1997a, 1997b, 1998a, 1998b), or differences in the property rights of the resources (Chichilnisky, 1994). This paper proposes a different approach, as the natural resource has an influence not only on international trade, but also on the distribution of firms among countries, which is endogenously determined. In turn, the distribution of economic activity also affects the equilibrium stock of the natural resource. In a related research, Takatsuka et al. (2015) study how resource development affects the industrialization of cities and regions using a New Economic Geography theoretical framework with transport costs. Our model offers a new complementary perspective, adding an endogenous growth mechanism.

The next section presents the basic characteristics of the theoretical model. Section 3 describes the market equilibrium of differentiated goods, with special attention given to the distribution of firms in the equilibrium. Section 4 describes the natural resource market and solves the corresponding equilibrium. Section 5 determines the steady state growth rate, which depends on geography, and also shows how economic growth in turn influences geography through income inequality. Once the general equilibrium is described, Section 6 analyses the effect of changes in populations, innovation and transport costs. Finally, the paper ends with the main conclusions.

2. The model

We consider two countries, North and South, which trade with each other. Since both are almost identical, we will focus on describing the economy of the North (an asterisk denotes the variables corresponding to the South). The only differences are the initial level of capital, K_0 in the North and K_0^* in the South, with $K_0 > K_0^*$, and the presence of a natural resource only in the South (the results prevail when the North is also endowed with the natural resource as long as we keep a relative abundance in the South).

Preferences

Let L denote the population size (and labour supply) in each country. Individuals are mobile between sectors but immobile between countries. Their preferences are instantaneously nested CES, and intertemporally CES, with an elasticity of intertemporal substitution equal to the unit:

$$U = \int_0^\infty \log\left[D(t)^\alpha Y(t)^{1-\alpha}\right] e^{-\rho \cdot t} dt, \qquad 0 < \alpha < 1, \qquad (1)$$

where ρ is the intertemporal discount rate, Y is the numeraire good, and D is a composite good which, in the style of Dixit and Stiglitz, consists of a number of N different varieties:

$$D(t) = \left[\int_{i=0}^{N(t)} D_i(t)^{1-\frac{1}{\sigma}} di\right]^{\frac{1}{\left(1-\frac{1}{\sigma}\right)}}, \qquad \sigma > 1. \qquad (2)$$

with σ capturing the elasticity of substitution between varieties.

Transport costs

The numeraire good Y is not subject to transaction costs when moved from one country to the other. However, trade of the differentiated good is subject to a transport cost $\tau > 1$ and trading of the natural resource (from South to North) is also subject to a transport cost $\tau_R > 1$. τ and τ_R represent iceberg-type costs, as in Samuelson (1954). Thus, only $\tau^{-1} < 1$ ($\tau_R^{-1} < 1$) of each unit of a differentiated variety (of the natural resource) sent from one country is available in the other. Decreases in τ or τ_R facilitate trade. We assume $\tau_R \le \tau$: it is equal or less costly to trade the natural resource than the differentiated good (the results do not change in the reverse case, assuming that the difference is not very high).

Industry

The numeraire good is produced using only labour, subject to constant returns, in a perfectly competitive sector, with the unit cost of labour normalized to 1. In contrast, the differentiated goods are produced with identical technologies in an industry with monopolistic competition and increasing scale returns. To start the production of a variety x_i, a unit of capital is needed; this fixed cost (FC) is the source of the scale economies. Labour (L) and natural resource (R) are combined through a Cobb-

Douglas type technology, $x_i = L_i^{1-\mu} R_i^{\mu}$, with $\mu \in (0,1)$ measuring how intensive the technology is in the use of the resource.

Capital

The number of varieties produced in each country, n and n^*, is endogenous, with $N = n + n^*$. In order to produce a new variety a previous investment is required, either in a physical asset (machinery) or an intangible one (patent). As in Martin and Ottaviano (1999), the concept of capital used in this paper corresponds to a mixture of both types of investment. We assume that each new variety requires one unit of capital. The total number of varieties and firms is determined by the aggregate stock of capital at any given time: $N = n + n^* = K + K^*$. Once the investment is made, each firm produces the new variety in a situation of monopoly and chooses where to locate its production, as there are no costs of relocating the capital from one country to the other.

Finally, we assume there is a safe asset which pays an interest rate r on units of the numeraire; free mobility of this asset between countries ensures $r = r^*$.

Innovation

Growth comes from the increase in the number of varieties as a result of the effort devoted to the R&D sector. This activity requires labour and is subject to national spillovers: the more firms producing different manufactured goods in a country, the less costly is R&D[2]. This sector follows Grossman and Helpman (1991), with η / n being the cost in terms of the labour of an innovation in the North and η / n^* in the South. The immediate implication is that research activity will only take place in the country where more firms are located: the North[3]. This formulation makes the analytical treatment of the model easier, although the results are maintained even if a certain degree of diffusion of knowledge exists at the international level (Hirose and Yamamoto, 2007).

Natural resource

The South is endowed with a stock S of a renewable, open access natural resource, characterized as in Eliasson and Turnovsky (2004) or in Brander and Taylor

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[2] This type of knowledge spillovers is closer to the concept of Jacobs (1969) than to that of Marshall-Arrow-Romer (MAR). The empirical evidence for these external effects between different industries in the same geographical unit is documented; see, for example, Glaeser et al. (1992) and Henderson et al. (1995).

[3] Below it is shown that this result holds as long as $K_0 > K_0^*$, as we have supposed.

(1997a, 1997b, 1998a, 1998b). At any point of time, the net change in the stock of the resource is given by $\dot{S} = G(S) - R$, where $G(S)$ is a concave function that describes the natural growth of the resource and R is the harvested amount. $G(S)$ 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 its properties). We assume a logistic function, which has been widely used in the literature:

$$G(S) = \gamma S\left(1 - \frac{S}{\overline{S}}\right), \qquad \gamma > 0 \qquad (3)$$

where γ is the intrinsic growth rate of the resource (the natural growth rate). In the absence of harvesting, S converges to its maximum sustainable stock level $\overline{S}$.

The harvest of the natural resource requires only labour. We assume that harvesting is carried out according to the Schaefer harvesting production function:

$$R = BSL_R\,, \qquad (4)$$

where R is the amount harvested or the natural resource supply at any moment in time, L_R is the amount of (Southern) labour devoted to obtaining the resource and B is a positive constant. According to (4), the unit labour requirement in the resource sector is given by $(BS)^{-1}$; thus, the labour requirement increases as the stock of the resource decreases.

3. Equilibrium distribution of firms

Consumers

The value of per capita expenditure E in terms of the numeraire Y is:

$$\int_{i\in n} p_i D_i di + \int_{j\in n^*} \tau p_j^* D_j dj + Y = E\,, \qquad (5)$$

where p and p^* denote the price of any variety produced in the North or in the South, respectively. Solving the first order conditions of the problem of the consumer in the North we obtain the demand of an individual in the North for each variety produced in the North (D_i), in the South (D_j), and for the numeraire good:

$$D_i = \frac{\sigma - 1}{\beta\sigma} \cdot \frac{\left((\tau_R p_R)^{\mu}\right)^{-\sigma} \alpha E}{\left(n\left((\tau_R p_R)^{\mu}\right)^{1-\sigma} + n^{*}\delta\left(p_R^{\mu}\right)^{1-\sigma}\right)} \tag{6}$$

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

$$Y = (1-\alpha)E \tag{8}$$

where $\delta = \tau^{1-\sigma}$ is a parameter between 0 and 1 that measures the openness of trade: $\delta = 1$ represents a situation in which transport costs do not exist, while if $\delta = 0$ trade would be impossible due to the high transaction costs. Equivalent expressions can be obtained for the demands of an individual in the South.

The intertemporal optimization of consumers implies that the growth rate of expenditure, either in the North or in the South, is given by the difference between the interest rate and the intertemporal discount rate: $\frac{\dot{E}}{E} = \frac{\dot{E}^{*}}{E^{*}} = r - \rho$. As we will show below, in the steady state E and E^{*} will be constant, so $r = \rho$.

Industry

As labour is mobile between sectors, the constant returns and free competition in the production of the numeraire good tie down the wage rate in both countries to $w = 1$. We assume throughout the paper that the parameters of the model are such that the numeraire is produced in both countries, that is, that the total demand for the numeraire is big enough so as not to be satisfied by its production in a single country. In this way, wages are maintained constant and identical in both countries over time.

In the differentiated goods industry, the location of the resource only in the South makes firm costs different between countries. The cost function of a representative firm in the North is $c = FC + \beta x q$, with, $\beta = \mu^{-\mu}(1-\mu)^{\mu-1}$, while that of a firm in the South is $c = FC + \beta x q^{*}$, where $q = w^{1-\mu}(\tau_R p_R)^{\mu}$ and $q^{*} = w^{1-\mu} p_R^{\mu}$ are the price indexes and p_R denotes the market price of the natural resource, and x and x^{*} are the production scale of a firm in the North and in the South, respectively (the amount produced for any variety in one country is the same due to the symmetry of the problem). The standard rule of monopolistic competition determines the price of any variety which, taking into account that $w = 1$, are given by $p = \beta\left(\frac{\sigma}{\sigma - 1}\right)(\tau_R p_R)^\mu$ and $p^* = \beta\left(\frac{\sigma}{\sigma - 1}\right)p_R^\mu$ for any variety produced in the North or in the South, respectively. Note that, since the South firms do not bear the transport cost in the natural resource, they enjoy a competitive advantage in costs.

As a consequence, the operating profits of the firms are also different depending on the country where they are located:

$$\pi = px - \beta xq = \left(\frac{\beta x}{\sigma - 1}\right)(\tau_R p_R)^\mu \qquad (9)$$

in the North, and

$$\pi^* = p^* x^* - \beta x^* q^* = \left(\frac{\beta x^*}{\sigma - 1}\right)p_R^\mu \qquad (10)$$

in the South.

The location of firms in equilibrium is determined by four conditions. The first two refer to the fact that when differentiated goods are produced in both countries, total demand, from both North and South, for each variety (including transport costs) must equal supply. Thus, from (6) and (7):

$$x = \frac{\alpha L(\sigma - 1)}{\beta\sigma} \cdot \left((\tau_R p_R)^\mu\right)^{-\sigma} \cdot \cdot \left(\frac{E}{N\left(S_n\left((\tau_R p_R)^\mu\right)^{1-\sigma} + (1 - S_n)\delta\left(p_R^\mu\right)^{1-\sigma}\right)} + \frac{\delta E^*}{N\left(S_n\delta\left((\tau_R p_R)^\mu\right)^{1-\sigma} + (1 - S_n)\left(p_R^\mu\right)^{1-\sigma}\right)}\right) \qquad (11)$$

$$x^* = \frac{\alpha L(\sigma - 1)}{\beta\sigma} \cdot \left(p_R^\mu\right)^{-\sigma} \cdot \cdot \left(\frac{E^*}{N\left(S_n\delta\left((\tau_R p_R)^\mu\right)^{1-\sigma} + (1 - S_n)\left(p_R^\mu\right)^{1-\sigma}\right)} + \frac{\delta E}{N\left(S_n\left((\tau_R p_R)^\mu\right)^{1-\sigma} + (1 - S_n)\delta\left(p_R^\mu\right)^{1-\sigma}\right)}\right) \qquad (12)$$

where $S_n = n / N$ is the share of varieties of the manufactured good produced in the North.

The third condition is the consequence of the free movements of capital between countries ($r = r^*$), which implies an equal retribution via profits:

$$\pi = \pi^*, \quad (13)$$

and, therefore, according to (9) and (10), $x = x^* / \tau_R^{\mu}$. Finally, the fourth condition equals the total number of varieties to the worldwide supply of capital at each moment:

$$n + n^* = K + K^* = N. \quad (14)$$

Solving the system formed by these four equations, we obtain the size of each firm in equilibrium in the North and in the South as:

$$x = \frac{\alpha L(\sigma - 1)}{\beta\sigma} \cdot \frac{(E + E^*)}{N} \cdot (\tau_R p_R)^{-\mu}, \quad (15)$$

$$x^* = \frac{\alpha L(\sigma - 1)}{\beta\sigma} \cdot \frac{(E + E^*)}{N} \cdot p_R^{-\mu}. \quad (16)$$

Note that the demand of any variety increases with population and the equilibrium production scales are different in each country: locating in the North implies an additional cost due to the transport of the natural resource, and the firms react by producing fewer units of their varieties at a higher price.

The proportion of firms in the North ($S_n = n / N$) is given by:

$$S_n = \frac{S_E}{(1 - \delta \cdot \phi_R)} - \frac{\delta(1 - S_E)}{(\phi_R - \delta)}, \quad (17)$$

where, in turn, $S_E = \frac{E}{E + E^*}$ is the participation of the North in total expenditure and $\phi_R = \tau_R^{\mu(1-\sigma)}$ is a parameter between 0 and 1 of similar interpretation to δ, measuring the freedom of trade of the natural resource. It is also possible to demonstrate that, as long as the North has a larger domestic market[4] ($S_E > 1/2$), most firms are located in the North ($S_n > 1/2$).

On one side, the location of the firms in equilibrium depends on national expenditure: higher local expenditure means a larger domestic market, which attracts more firms wanting to take advantage of increasing returns (home market effect). On the other, it is influenced by the openness of trade of differentiated goods δ and of the natural resource ϕ_R. Given that, by definition, $\phi_R > \delta$ holds, the transport cost of the

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[4] $K_0 > K_0^*$ ensures that $S_E > 1/2$, see Equation 23.

natural resource pushes the firms to locate in the South; thus, the lower this transport cost, the smaller the advantage for firms to locate in the South.

4. Equilibrium in the natural resource sector

Production in this sector is carried out by profit-maximizing firms operating under conditions of free entry (perfect competition). Therefore, the price of the resource good must equal its unit production cost:

$$p_R = \frac{w}{BS} = \frac{1}{BS}. \qquad (18)$$

The firms in the sector of the differentiated goods demand the natural resource as an input in the production of their varieties. Applying Shephard's lemma to the cost functions, we obtain the demand for the natural resource: $\beta x \cdot \mu(\tau_R p_R)^{\mu-1}$ for a representative firm of the North and $\beta x^* \cdot \mu p_R^{\mu-1}$ for a representative firm of the South. Substituting the equilibrium production levels given by (15) and (16), the price of the resource from (18) and aggregating for the firms in the North (taking into account the transport cost they bear) and in the South, we obtain the worldwide demand for the resource, from which we obtain the resource market equilibrium condition:

$$R = \mu BS \cdot \frac{\alpha(\sigma-1)}{\sigma} \cdot L(E+E^*). \qquad (19)$$

Note that the amount of the natural resource harvested in equilibrium increases with the aggregate world income $L(E+E^*)$, that is to say, a higher amount of the resource is harvested after an increase in population and/or individual income. According to (3), the steady state is reached when the amount harvested equals its capacity for reproduction: $G(S) = R$. A trivial solution is reached when $S = R = 0$. The other solution is given by:

$$\tilde{S} = \bar{S}\left[1 - \mu B \cdot \frac{\alpha(\sigma-1)}{\gamma\sigma} \cdot L(E+E^*)\right]. \qquad (20)$$

As shown by Brander and Taylor (1997a), a positive steady state solution exists if and only if the term between brackets is positive, that is to say, if the condition $\mu B \cdot \frac{\alpha(\sigma-1)}{\sigma} \cdot (E+E^*) < \frac{\gamma}{L}$ holds. In this case the solution is globally stable.

In what follows we go further in solving the model by considering growth and income distribution issues. In fact, we will reduce the solution to two equations involving the variables g and S_n.

5. Steady state

Labour market equilibrium

We will first examine the growth rate of the economy. Starting from the solution of the problem of the intertemporal optimization of the consumer, we know that, in equilibrium, $\frac{\dot{E}}{E} = \frac{\dot{E}^*}{E^*} = r - \rho$. As the capital flows are free, $r = r^*$, and the expenditure growth rate will be the same in both countries. From (17), this implies that the ratio of firms producing in the North, S_n, is also constant in time, and, therefore, n, n^* and N grow at the same constant rate g.

The value of the firm v is given by the value of its unit of capital. As the capital market is competitive, this value will be given by the marginal cost of innovation, $v = \frac{\eta}{n} = \frac{\eta}{NS_n}$, which is therefore decreasing at a rate g: $\frac{\dot{v}}{v} = -g$. As the number of varieties increases, the profits of each firm decrease, and so does its value, which can also be interpreted as the future flow of discounted profits $\left(v(t) = \int_t^{\infty} e^{-[\bar{r}(s) - \bar{r}(t)]} \frac{\beta x(s)}{\sigma - 1} ds \right)$, where $\bar{r}$ represents the cumulative discount factor. Taking into account the *arbitrage condition between the capital market and the safe asset market*, the relationship between the interest rate and the value of the capital is given by[5]:

$$r = \frac{\dot{v}}{v} + \frac{\pi}{v} \quad (21)$$

On the other hand, the constraint of world resources, $E + E^* = 2 + (r\eta)/(LS_n)$, where the right-hand includes the sum of labour income ($w = 1$ in the two countries)

[5] This condition is formulated in terms of the profits of the firms in the North (π), but applies in the same way to the South because, although the expressions of π and π^* differ (Equations 9 and 10), one of the conditions of equilibrium (Equation 13) requires that $\pi = \pi^*$.

and capital returns, implies that worldwide expenditure is constant over time, so that in steady state, $r = \rho$, as indicated above. Note that this restriction includes only labour and capital returns; the harvest of the natural resource does not generate additional income for either of the two countries, as it is an open access resource exploited in a competitive industry.

Finally, we must take into account the labour market. The world's labour is devoted to R&D activities (using only workers from the North), and to the production of goods. From the latter, a proportion $(1-\alpha)$ is dedicated to the production of the numeraire good, and a proportion α to the production of differentiated goods. In turn, given the Cobb-Douglas technology properties, from the labour used, either directly or indirectly, in the production of manufactured goods, a proportion μ is used in the exploitation of the resource (using only workers in the South), and a proportion $1-\mu$ is used directly as an input in the production of varieties. Thus, the world labour market equilibrium condition is given by:

$$\eta \frac{g}{S_n} + \left(\frac{\sigma - \alpha}{\sigma} \right) L(E + E^*) = 2L \ . \qquad (22)$$

In steady state, all the variables grow at a constant rate. Replacing in (21) the profits obtained in (9), the optimum size of firms in the equilibrium (15), and considering (22) and that in steady state $r = \rho$, we obtain the *labour and capital markets equilibrium condition* (LME):

$$g = \frac{2L}{\eta} \cdot \frac{\alpha}{\sigma} S_n - \left(\frac{\sigma - \alpha}{\sigma} \right) \rho \ . \qquad (23)$$

which relates the rate of growth and the distribution of firms in a positive (linear) way.

World income distribution

As stated before, the demand for any variety depends on the distribution of income between both countries. This is why we start by identifying the sources of income. The per capita income of each country is the sum of labour income (which, as we have already seen, is the unit), plus the capital income, which is *r* times the value of per capita wealth. Thus, $E = 1 + r\frac{Kv}{L} = 1 + \rho\frac{Kv}{L}$ for any individual in the North. If we replace v from the arbitrage condition between the capital market and the safe asset market (21), the equilibrium profits (9), and the optimum production scale (15), it is possible to express Northern expenditure as a function of the growth rate g :

$$E = 1 + \frac{2\alpha\rho S_K}{(\sigma-\alpha)\rho + \sigma g}, \tag{24}$$

where $S_K = \frac{K}{K+K^*}$ is the share of capital owned by the individuals in the North, that remains constant because K and K^* grow at the same rate g in the steady state (S_K>1 because we assume $K_0 > K_0^*$). Similarly, for the South:

$$E^* = 1 + \frac{2\alpha\rho(1-S_K)}{(\sigma-\alpha)\rho + \sigma g}. \tag{25}$$

From (24) and (25), the participation of the North in worldwide income is given by:

$$s_E = \frac{E}{E+E^*} = \frac{1}{2}\cdot\frac{\sigma(\rho+g)+\alpha\rho(2S_K-1)}{\sigma(\rho+g)}. \tag{26}$$

Note that our assumption $S_K > 1/2$ implies $S_E > 1/2$. However, the relationship of s_E with the economic growth rate is negative: as the number of varieties increases, the value of the capital is reduced, which in turn reduces capital income, which is higher in the North; thus, the income difference is reduced in relative terms. Using (17) and (26), the equilibrium s_n can be obtained from a quadratic equation (see details in the Appendix). Finally, by carrying (26) to (17) we obtain the *differentiated goods market equilibrium condition* (DME), relating again the distribution of firms with the growth rate:

$$s_n(g) = \frac{1}{2(1-\delta\cdot\phi_R)(\phi_R-\delta)}\left[(1+\delta^2)\phi_R - 2\delta + (1-\delta^2)\phi_R\cdot\frac{\alpha\rho(2S_k-1)}{\sigma(\rho+g)}\right]. \tag{27}$$

Thus far, we have obtained two equations, (23) and (27), representing, respectively, the *labour and capital markets equilibrium condition* and the *differentiated goods market equilibrium condition*. These functions relate the growth rate with the spatial distribution of firms, and define the equilibrium values of these variables. Since the algebraic solution is not easy, we follow a graphical approach.

The function (23) is linear and increasing: given the nature of the technological spillovers (national), the greater the concentration of firms, the lower the costs of innovation and the higher the growth rate. The function (27) is convex and decreasing[6]. Remember that this equation incorporates the inequality of income, and that this decreases as g increases via the reduction of monopolistic profits of firms. At the same time, as the differences in income vanish, industrial concentration and the market size of the rich country decrease due to the home market effect.

These functions are represented in Figure 1. The intersection point determines the steady state location of firms as well as the growth rate of the economy.

6. Growth and natural resources

Speeding up growth

An increase in the growth rate of the economy can come from different sources. Let us highlight three of them: first, an increase in global demand due to an increase in the population in both countries ($dL = dL^* > 0$); second, a reduction in innovation costs ($d\eta < 0$) which enhances growth, given that the R&D sector is the source of such economic growth; and, finally, a reduction in the transport cost of the natural resource ($d\tau_R < 0$). The two former sources affect the labour market equilibrium (LME): after an increase in L or a decrease in η this function moves downwards and changes its slope, leading to a faster growth rate and a reduction in the concentration of firms in the North (see Figure 2). In turn, the reduction in transport costs moves the differentiated goods market equilibrium (DME) upwards, increasing both the growth rate and the proportion of firms located in the North (Figure 3). However, the consequences for the natural resource are not related with the function that moves, as we show below, giving rise to a non-monotonic relationship between growth and the use of the natural resource.

Apart from the direct effects of some variables that can be easily derived from (19) and (20), any variation in the distribution of firms and/or in the economic growth rate will also change the stock of the resource in steady state. Note that both the harvest level in (19) and the stock of the resource in equilibrium in (20) depend on the

[6] The DME function (Equation 27) is convex and decreasing as long as $(\phi_R - \delta) > 0$. This condition is verified if $\tau_R \leq \tau$, as we have been assuming from the beginning. Additionally, $(\phi_R - \delta)$ is greater than zero even when the transport cost for the resource is higher than that of the differentiated good, as long as the difference is not too great.

aggregate world income $L(E+E^*)$. By combining (9), (15) and (21), such world income can be related to S_n and g:

$$L(E+E^*)=\frac{\eta\sigma(\rho+g)}{\alpha S_n}. \tag{28}$$

If we replace this expression in (19) and (20) we obtain:

$$S=\overline{S}\left[1-\mu B\cdot\frac{(\sigma-1)}{\gamma}\cdot\frac{\eta(\rho+g)}{S_n}\right], \tag{29}$$

$$R(S)=\mu BS\cdot(\sigma-1)\cdot\frac{\eta(\rho+g)}{S_n}. \tag{30}$$

From these expressions we can analyse the effects on the natural resource, including changes in the growth rate and the distribution of firms.

An increase in population

Possibly the most important pressure on natural resources in our world is growth in population. In this model, an equal increase in population in both countries ($dL=dL^*>0$) leads to an increase in aggregate demand for the consumption goods, both the numeraire and any variety of the differentiated good (see Equations 15 and 16). A higher demand for the different varieties, in turn, translates to the inputs required in its production, in particular to the natural resource, which is evident from (19) for given amounts of individual incomes E and E^*. The higher demand in the intermediate sector also increases profits, which spurs innovation, speeding up the rate of growth ($dg>0$). However, the accelerated innovation inevitably involves a Schumpeterian phenomenon of creative destruction: the stronger competition among firms diminishing the flow of profits, reducing at a faster rate the value of the firms and the monopolist rents obtained by their owners.

This effect compensates (partially) the increase in population in the aggregate world income $L(E+E^*)$. But it also has reallocation consequences: since the capital income is mainly concentrated in the North, a reduction in capital rents weakens the home market effect in this country (reducing the participation of the North in worldwide income, $\frac{dS_E}{dg}<0$) leading to a movement of firms towards the South (see Figure 2).

According to (29) and (30), the increase in the growth rate (more firms producing varieties require more natural resource) and the reallocation to the South (firms in the south use the natural resource more intensely due to the absence of trade costs) are two forces in the same direction: towards a higher depletion of the natural resource:

$$dS = -\bar{S}\mu B \cdot \frac{\alpha(\sigma - 1)}{\gamma\sigma} \cdot \left(E + E^{*}\right) dL < 0 \, .$$

A reduction in innovation cost

When thinking about speeding up growth, one typical solution involves enhancing R&D activities. In our framework, this can be easily captured as a reduction in the costs of innovation η ($d\eta < 0$).

The immediate effect is clear: lower costs in the R&D sector lead to an increase in the demand for labour, which speeds up its output: new varieties are now developed at a faster rate and the whole economy grows faster, as Figure 2 shows. The influence on the natural resource is not so clear because its demand is subject to opposite forces. The lower costs lead to a reduction in the value of the R&D firms and the rents of capital because the production of each differentiated good depends inversely on the total number of varieties (see Equations 15 and 16). By substituting the growth rate (20) in the aggregate world income (25) we have $L(E + E^{*}) = 2L + \rho \dfrac{\eta}{S_n}$. Thus, for a given distribution of firms, the aggregate income falls, leading in a first stage to a lower demand for intermediate goods and for the natural resource. Moreover, as in the previous case, world inequality decreases ($dS_E < 0$) promoting a reallocation of firms to the South ($dS_n < 0$), where production is more intensive in the use of the resource, which increases its aggregate demand. However, it can be shown that the higher pressure on the natural resource due to the faster growth rate and the presence of more firms in the South does not compensate the initial effect due to the fall in the demand for all the varieties and finally the stock of the natural resource increases in the new steady state:

$$dS = \bar{S}\mu B \cdot \frac{\eta(\sigma - 1)}{\gamma S_n} \cdot \left(\frac{\alpha\rho}{\sigma}\right) \left[\frac{dS_n}{S_n} - \frac{d\eta}{\eta}\right] > 0 \, .$$

The positive sign comes from the fact that the growth rate clearly increases (see Figure 2), which from (23) indicates that $\left|\frac{dS_n}{S_n}\right| < \left|\frac{d\eta}{\eta}\right|$.

A reduction in trade costs

A lower transport cost of the natural resource ($d\tau_R < 0$) means a loss in the cost advantage of the firms located in the South, close to the natural resource, over those located in the North. As a consequence of this decrease in relative costs in the North, firms move from the South to the North, which has a bigger domestic market and greater demand. Moreover, as the number of firms in the North increases, the cost of research decreases due to national spillovers, and the economic growth rate increases (Figure 3). At the limit, if this transport cost did not exist ($\tau_R = 1$) the firms could not extract any advantage from its location close to the resource and there would be no relationship between the distribution of the natural resource and the economic geography.

By differentiating (29), we obtain the effect of the reduction in transport costs on the stock of the natural resource in steady state:

$$dS = -\bar{S}\mu B \cdot \frac{(\sigma - 1)}{\gamma} \cdot \eta \frac{1}{S_n} \left[dg - \frac{1}{S_n}(\rho + g) dS_n \right].$$

This expression enables us to identify two opposite effects. First, an industry localization effect: as the number of firms located in the North increases, the amount of the resource which is harvested decreases, because the firms in the North produce less units of differentiated good and thus require a lower amount of the natural resource. Second, a growth effect: as the number of firms in the North increases, due to the spillovers the growth rate of the number of varieties also increases and the number of firms grows faster. More firms require a higher amount of the natural resource.

However, applying that, from (23), $dg = \frac{2L}{\eta} \cdot \frac{\alpha}{\sigma} dS_n$, it is possible to obtain a clear sign:

$$dS = -\bar{S}\mu B \cdot \frac{(\sigma - 1)}{\gamma} \cdot \eta \frac{1}{S_n^2} \left[\frac{-\alpha}{\sigma} \rho \right] dS_n > 0,$$

indicating that the firm localization effect dominates: more firms in the North means that less resource is consumed on average, enabling the level of stock to increase in steady state.

7. Conclusions

In this paper, we present a model integrating characteristics of the New Economic Geography, the theory of endogenous growth, and the economy of natural resources. Geography enters the model via transport costs, which condition the distribution of firms which attempt to take advantage of increasing returns in a market of monopolistic competition. Economic growth is supported by national spillovers in innovation, and the natural resource appears as a localized input in one of the two countries (the South), subject to trade costs, which gives firms located closely a cost advantage.

In such a framework, we discuss the relationship between economic growth and the evolution of the natural resources endowment at a global scale. The industrial revolution opened an age of economic growth accompanied by an increasing demand for natural resources. Indeed, the consequence of economic activity on the environment has become one of the key global challenges in the last century and today it still seems far from being resolved. In this paper, we show that the impact of economic growth on natural resources is not necessarily negative, but depends on the specific elements that drive such growth.

Demographic expansion is one element behind the increase in worldwide GDP, which is usually associated with a high exploitation of natural resources, even leading to a critical depletion of some of them. We confirm this result, supporting the consideration of economic growth as a threat for the environment. However, we have found that such negative relationship does not always hold, particularly when the geography matters.

Geography matters because neither natural resources nor economic activity are homogenously distributed. The closer the industry locates to the natural resources, the higher the exploitation of such resources. As we found, a reduction in trade costs favours a concentration of industry far from the natural resources area and, despite it also speeding up economic growth, the reallocation of industry acts against natural resources depletion.

Schumpeterian creative destruction is another element that interferes with the influence of economic activity on the environment: when growth is driven by the R&D sector, an increase in the productivity of this sector leads to an expansion in the diversity of goods and firms which, as a result of the deeper competition, cuts down capital rents and, thus, global demand. The geographical reallocation of firms in this case has a negative influence on resource conservation, since the firms move closer to the natural resource location, although this effect does not compensate the global fall in demand. As a result, a faster growth coexists with a higher stock of natural resources.

Thus, an increase in the world growth rate can be a source of higher pressure on the natural resource and lead to a higher depletion. This is the case after an increase in the world demand, which we have identified as an increase in population. However, the consideration of geography and growth mechanisms make the relationship between growth and natural resources more complex, and can even lead to the opposite conclusion when the forces behind growth are different from world demand. One key element in the economic geography models, namely the transport costs, and another key element in the economic growth models, namely the R&D costs, appear to be able to generate a faster growth without diminishing the natural resources; and even more importantly, can make faster growth compatible with a lower depletion of natural resources.

We are aware that these results rely on the particular characteristics of the natural resource considered in our model, in particular that it is renewable and open access. These assumptions have enabled us to build the simplest possible model in analytical terms. However, since at present most natural resources used in the production of manufactured goods are derived from oil or mining, it would be interesting to analyse how our model changes when the natural resource is not renewable. Furthermore, if the resource was not open access, property rights would generate additional income which could also influence the results.

Appendix: Steady state equilibrium

The value of S_n in the steady state is the solution of this quadratic equation:

$$\begin{aligned}&(1-\delta\cdot\varphi_R)(\varphi_R-\delta)2L\cdot S_n^2+\\&+S_n\left[(1-\delta\cdot\varphi_R)(\varphi_R-\delta)\rho\eta-\left[(\varphi_R-\delta)+\delta(1-\delta\cdot\varphi_R)\right]L+2\delta(1-\delta\cdot\varphi_R)L\right]-\\&-\rho\eta\left(\left[(\varphi_R-\delta)+\delta(1-\delta\cdot\varphi_R)\right]S_k-\delta(1-\delta\cdot\varphi_R)\right)=0.\end{aligned}$$

The valid solution is given by:

$$S_n=\frac{[[(\phi_R-\delta)+\delta(1-\delta\cdot\phi_R)]L-(1-\delta\cdot\phi_R)(\phi_R-\delta)\rho\eta-2\delta(1-\delta\cdot\phi_R)L]+\sqrt{\Delta}}{4L(1-\delta\cdot\phi_R)(\phi_R-\delta)},$$

where

$$\begin{aligned}\Delta=&\left[(1-\delta\cdot\varphi_R)(\varphi_R-\delta)\rho\eta-\left[(\varphi_R-\delta)+\delta(1-\delta\cdot\varphi_R)\right]L+2\delta(1-\delta\cdot\varphi_R)L\right]^2+\\&+8L(1-\delta\cdot\varphi_R)(\varphi_R-\delta)\cdot\rho\eta\left(\left[(\varphi_R-\delta)+\delta(1-\delta\cdot\varphi_R)\right]S_k-\delta(1-\delta\cdot\varphi_R)\right).\end{aligned}$$

The other root is greater than the unit and thus has no economic meaning. From this equilibrium value of S_n, which indicates the location of firms, we can obtain the steady state growth rate g in (23), and the North share in aggregate expenditure S_E in (26).

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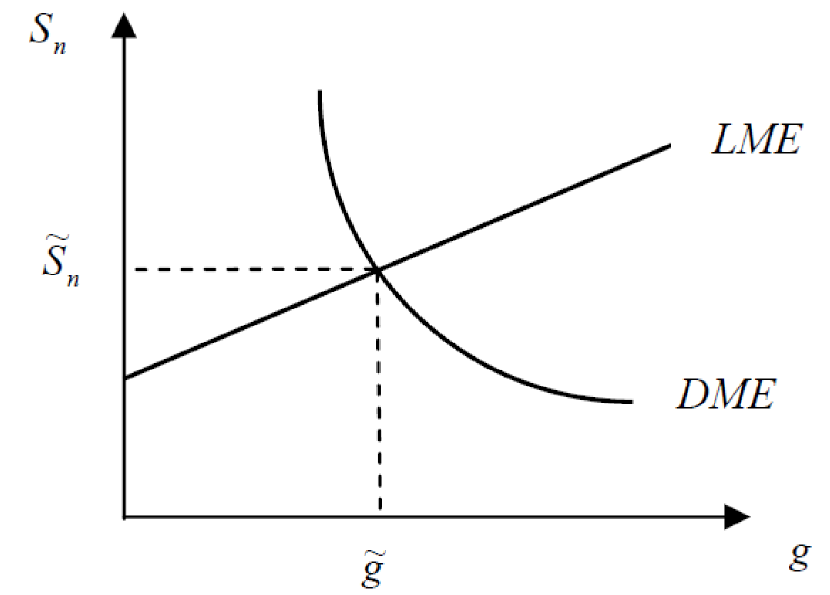
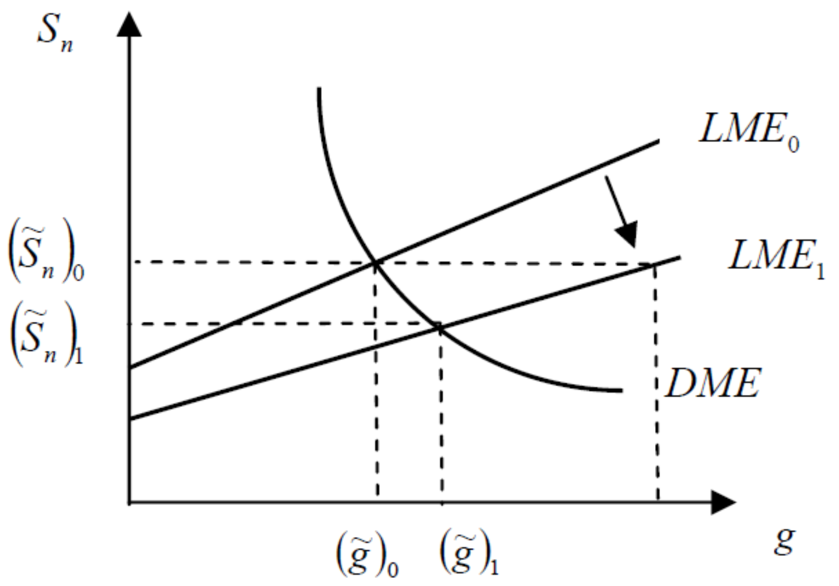
Figure 1. Steady state equilibrium



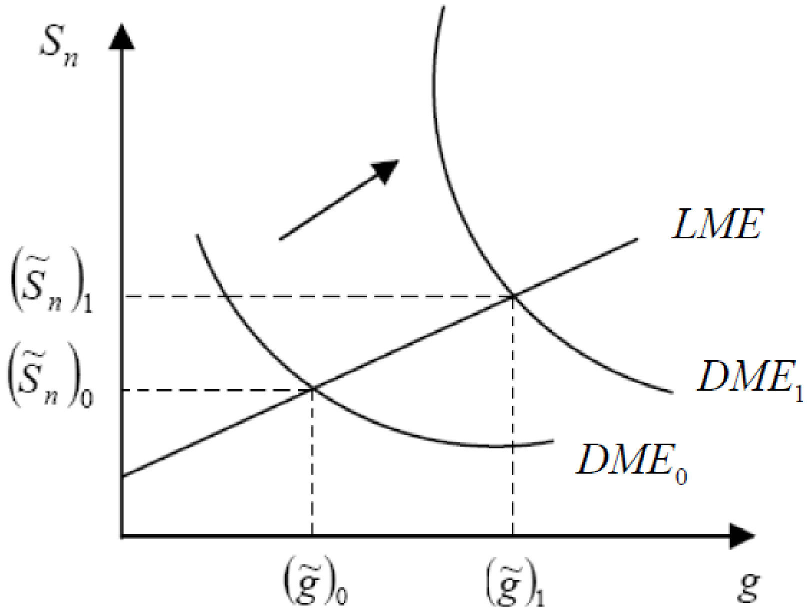
Note: LME is the labour and capital markets equilibrium condition (Equation 23) and DME is the differentiated goods market equilibrium condition (Equation 27).

Figure 2. Effects of an increase in population or a reduction in innovation costs



Note: LME is the labour and capital markets equilibrium condition (Equation 23) and DME is the differentiated goods market equilibrium condition (Equation 27).

Figure 3. Effects of a reduction in the transport cost of the natural resource



Note: LME is the labour and capital markets equilibrium condition (Equation 23) and DME is the differentiated goods market equilibrium condition (Equation 27).

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