Natural resources, economic growth and geography

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Abstract: Worldwide materials extraction increased by a factor of 8.4 over the course of the 20th century. In the meantime, global GDP and population increased by factors of about 22 and 4, respectively. This reveals that one of the key factors driving the increase in the exploitation of the resources was the growth in world population, although mitigated by the reduction in the intensity in the use of the resources in production. In this paper, we present a model that combines the theory of endogenous growth and the economy of natural resources, but taking into account the geographical distribution of economic activity. Indeed, the New Economic Geography provides insights about two elements that, although speeding up GDP growth, can curb the pressure on natural resources, namely the reduction in transports costs and a boost to pace of innovation.

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1. Introduction

Looking back at the world's performance along the 20th century from an economic view, possibly the main issue would be the great expansion in the production of goods and services, which has contributed to an age of improving human well-being. What drives economic growth? The usual answer is technological change. In this area, the work of Paul Romer, one of the 2018 Nobel Prize in Economic Sciences laureates, is specifically devoted to the role of R&D. From his seminal papers on endogenous growth (Romer, 1990), the key point is the presence of spillovers in the diffusion of knowledge. The work of this year's second Nobel laureate, Willian Nordhaus, places a counterweight to this optimistic outlook: economic performance is subject to several constraints often omitted but none the less important: the environmental threat. His arguments share with those of Romer the importance of spillovers, although in this case of a negative nature: the production processes involve the use or deterioration of natural resources.

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 2000, global extraction of materials amounted to around 50 billion tonnes–see Fischer-Kowalski et al. (2011) for a review of several data sets. Materials include biomass, fossil energy carriers, ores and industrial minerals, and construction minerals. Krausman et al. (2009) elevates this figure to 59 billion tonnes in 2005, remarking that this implies that aggregate material extraction has increased by a factor of 8.4 from the beginning of the 20th century (the evolution of some specific materials is more outstanding: construction minerals extraction is multiplied by 34 and ores and industrial minerals by 27).

According to the Maddison Project Database 2018 (Bolt et al., 2018), over the 20th century world GDP increased at an average annual rate of about 3% and world population was quadruplicated. This implies that the material intensity in GDP at the beginning of the 21st century was less than the 40% of its value in 1900. However, when compared to the path of population the picture is very different: *per capita* material extraction doubled. Thus, the gains in the efficiency in the use of materials are overcome by the increasing pressure from population growth on the environment.

The negative relationship between population and environment has been long known; from the traditional Malthusian view to the popular IPAT equation (I = PAT) formulated by Ehrlich and Holden (1971), which relates Impact (e.g., natural resource use) to Population, Affluence (usually using *per capita* income as a proxy) and Technology. In the case of renewable natural resources, Cropper and Griffiths (1994) examined the link between population growth and deforestation, finding that rural population density increases deforestation. They argue that, while there is no question that population growth contributes to environmental degradation, its effects can be modified by economic growth and modern technology. In the same way Carson (2010) indicates that some economists engaged this debate by supporting the Environmental Kuznets Curve: technological progress is a large positive influence that is resource conserving, and a sufficiently high growth rate could offset the negative impact of population growth.

A key feature of natural resources is their heterogeneous geographical distribution. Their availability is usually concentrated in particular areas of the world that do not necessarily coincide with the areas where they are incorporated to production, giving rise to an important volume of trade. The amount of natural resources traded reached 3.7 trillion United States (US) dollars in 2008 (Ruta and Venables, 2012), after a ten-fold increase in the preceding decade. This implies that nowadays approximately one-fifth of worldwide trade merchandise is the trade in natural resources. As a reflect of their uneven geographical distribution, natural resources clearly dominate exports in developing countries, whereas their proportion is much lower in developed countries: in the Middle East and African countries natural resources amount to more than a 70% of total exports, against less than a 20% in North-America, Asia and Europe. Moreover, technological advances in transport and information technology have dramatically reduced the costs of moving merchandise over long distances: natural resources transport costs declined over 90% in real terms between 1870 and 2000 (WTO, 2010).

The literature on the incidence of trade on the pace of (renewable) natural resources tends to be generally pessimistic: the usual conclusion states that the expansion of trade spurs the diminution of the resources (Chichilnisky, 1994; Brander and Taylor, 1997a, 1997b, 1998a, 1998b; Karp et al., 2001). However, after making endogenous the enforcement of property rights, Copeland and Taylor (2009) found that this outcome should be relativized depending on both technological issues and government's policy design.

The aim of this paper is to go further into the relationship between economic growth and natural resources in a context of international trade, by making endogenous another element usually considered as given both by environmental and growth economists, namely the geographical distribution of production. The extraction of natural resources is immobile but the distribution of manufacturing firms is not, and firms' location decision is influenced not only by the proximity to the main markets but also by the distance to the productive inputs, natural resources being among them. Economic geography provides analytical tools to deal with these issues.

The economic geography literature identifies many factors that influence the distribution of economic activity. Locational fundamentals (geographical factors linked to the physical landscape, such as temperature, rainfall, access to the sea, or factor endowments of natural resources) are among the most important factors driving the geographic concentration of industrial activities, besides increasing returns to scale. Natural resources are especially important, because they are usually used as inputs in the production of manufactured goods. Kim (1995) may be viewed as a precursor in this empirical literature. After studying the relationship between the spatial concentration of the US industry and raw-material intensity in the late 19th and early 20th centuries, he concluded 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.

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) found 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.

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 uneven endowments of natural resources. In order to understand this role, we built a model that integrates characteristics of the New Economic Geography, the theory of endogenous growth and the economy of natural resources. It is closely related to that of 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 that follows the work of Helpman and Krugman (1985) and Krugman (1991). We additionally incorporate an open access renewable natural resource that is a necessary input for production but is unevenly distributed over space. Distance to natural resources arises as an additional element that conditions firms' decisions besides the traditional home market effect and the existence of trade costs. In a related work, Takatsuka et al. (2015) studied how resource development affects the industrialization of cities and regions using a New Economic Geography framework with transport costs. Our model offers a new complementary perspective by adding an endogenous growth mechanism, and is especially well suited to explain the effect on natural resources of some of the factors mentioned above, highlighted by the empirical literature: population growth, economic growth and trade.

The next section presents the basic characteristics of the theoretical model. Section 3 describes the market equilibrium of differentiated goods, with special attention 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. Once the forces that drive growth are identified, Section 6 analyses the effect of changes in population, innovation and transport costs on the stock of the natural resource, as well as the welfare effects of firm's spatial redistribution. 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 a higher level of capital in the North ($K > K^{*}$) and the presence of a natural resource only abundant 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 that $\tau_R \leq \tau$: 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 H are combined through a Cobb-Douglas type technology, $x_i = L_i^{1-\mu} H_i^{\mu}$, 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 that $r = r^*$.

Innovation

Growth comes from the increase in the number of varieties as a result of the effort devoted to the R&D sector[1]. 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

[1] In the natural resources literature one form of innovation is induced technological change, i.e., factor productivity augmentation whose speed has been encouraged by a policy instrument (Liu and Yamagami, 2018). Nevertheless, although some papers document a positive effect of induced technological change on natural resources, Nordhaus (2002) found a modest effect.

[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 because the level of capital is higher in the North by assumption, taking into account that the model has no transition (Grossman and Helpman, 1991).

certain degree of diffusion of knowledge exists at the international level (Hirose and Yamamoto, 2007).

Natural resource

The South is endowed with a stock R of a renewable, open access natural resource, characterized as in Eliasson and Turnovsky (2004) or in Brander and Taylor (1997a, 1997b, 1998a, 1998b). At any point of time, the net change in the stock of the resource is given by $\dot{R} = G(R) - H$, where $G(R)$ is a concave function that describes the natural growth of the resource and H is the harvested amount. $G(R)$ 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:

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

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

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

$$H = BRL_R, \qquad (4)$$

where H 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 $(BR)^{-1}$; 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 and in the South, the standard consumer demands can be obtained as shown in Appendix A. 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 that $r = \rho$.

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 large enough so as not to be satisfied by its production in a single country. In this way, wages are maintained at a constant value 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 $c = FC + \beta xq$, with, $\beta = \mu^{-\mu}(1-\mu)^{\mu-1}$, while that of a firm in the South is $c = FC + \beta xq^*$, where $q = w^{1-\mu}(\tau_R p_R)^{\mu}$ and $q^* = w^{1-\mu} p_R^{\mu}$ are the price indexes, 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 for 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:

$$\pi = px - \beta xq = \left(\frac{\beta x}{\sigma - 1}\right)(\tau_R p_R)^{\mu} \qquad (6)$$

in the North, and

$$\pi^* = p^* x^* - \beta x^* q^* = \left(\frac{\beta x^*}{\sigma - 1}\right) p_R^{\mu} \qquad (7)$$

in the South.

The location of firms in equilibrium is determined by four conditions (see again Appendix A). The first two refer to the fact that when differentiated goods are produced in both countries, the production of each variety must equal its aggregate demand from both countries. The third condition is the consequence of the free movement of capital between countries ($r = r^*$), which implies an equal retribution via profits: $\pi = \pi^*$ and, therefore, according to (6) and (7), $x = x^* / \tau_R^{\mu}$. Finally, the last condition implies that the total number of varieties must be equal to the worldwide supply of capital at each moment. By solving the equilibrium, we obtain the size of each firm in the North and in the South as:

$$x = \frac{\alpha L(\sigma - 1)}{\beta \sigma} \cdot \frac{\left(E + E^*\right)}{N} \cdot \left(\tau_R p_R\right)^{-\mu}, \qquad (8)$$

$$x^* = \frac{\alpha L(\sigma - 1)}{\beta \sigma} \cdot \frac{\left(E + E^*\right)}{N} \cdot p_R^{-\mu}. \qquad (9)$$

Note that the demand of any variety increases with population and, unlike in Martin and Ottaviano (1999), 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:

$$S_n = \frac{S_E}{\left(1 - \delta \cdot \phi_R\right)} - \frac{\delta\left(1 - S_E\right)}{\left(\phi_R - \delta\right)}, \qquad (10)$$

where, in turn, $S_E = \dfrac{E}{E + E^*}$ is the participation of the North in total expenditure. Also $\delta = \tau^{1-\sigma}$ 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; $\phi_R = \tau_R^{\mu(1-\sigma)}$ 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 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:

$$p_R = \frac{w}{BR} = \frac{1}{BR}. \qquad (11)$$

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 (8) and (9), the price of the resource from (11) 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:

$$H = \mu BR \cdot \frac{\alpha(\sigma - 1)}{\sigma} \cdot L(E + E^*). \qquad (12)$$

[4] A higher level of capital in the North ensures that $S_E > 1/2$, see Equation 19.

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

$$R=\overline{R}\left[1-\mu B\cdot\frac{\alpha(\sigma-1)}{\gamma\sigma}\cdot L\left(E+E^*\right)\right]. \tag{13}$$

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 $\mu B\cdot\frac{\alpha(\sigma-1)}{\sigma}\cdot\left(E+E^*\right)<\frac{\gamma}{L}$ 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 (10), 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]:

$$r = \frac{\dot{v}}{v} + \frac{\pi}{v} \ . \tag{14}$$

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) and capital returns, implies that worldwide expenditure is constant over time, so that in the 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:

$$\eta \frac{g}{S_n} + \left(\frac{\sigma - \alpha}{\sigma} \right) L(E + E^*) = 2L \, . \tag{15}$$

In the steady state, all the variables grow at a constant rate. Replacing in (14) the profits obtained in (6), the optimum size of firms in the equilibrium (8), and considering

[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 6 and 7), one of the conditions of equilibrium requires that $\pi = \pi^*$.

(15) and that in the steady state $r = \rho$, we obtain the *labour and capital markets equilibrium condition* (LME):

$$g = \frac{2L}{\eta} \cdot \frac{\alpha}{\sigma} S_n - \left(\frac{\sigma - \alpha}{\sigma} \right) \rho , \qquad (16)$$

which relates the rate of growth and the distribution of firms in a positive (linear) way.[6]

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) and 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 (14), the equilibrium profits (6), and the optimum production scale (8), it is possible to express Northern expenditure as a function of the growth rate g :

$$E = 1 + \frac{2\alpha\rho S_K}{(\sigma - \alpha)\rho + \sigma g} , \qquad (17)$$

where $S_K = \frac{K}{K + K^*}$ is the share of capital owned by the individuals in the North, which remains constant because both K and K^* grow at the same rate g in the steady state. Similarly, for the South:

$$E^* = 1 + \frac{2\alpha\rho(1 - S_K)}{(\sigma - \alpha)\rho + \sigma g} . \qquad (18)$$

From (17) and (18), the participation of the North in worldwide income is given by:

$$S_E = \frac{E}{E + E^*} = \frac{1}{2} \cdot \frac{\sigma(\rho + g) + \alpha\rho(2S_K - 1)}{\sigma(\rho + g)} . \qquad (19)$$

It can be shown that $S_E > 1/2$ as long as the North is better endowed in capital than the South ($S_K > 1/2$), as we assumed. However, the relationship of S_E with the economic

[6] Equation (16) is equivalent to Equation (14) in Martin and Ottaviano (1999).

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 (10) and (19), the equilibrium S_n can be obtained from a quadratic equation (see details in the Appendix B). Finally, by carrying (19) to (10) we obtain the *differentiated goods market equilibrium condition* (DME), relating again the distribution of firms with the growth rate:

$$S_n(g) = \frac{1}{2(1-\delta\cdot\phi_R)(\phi_R-\delta)}\left[(1+\delta^2)\phi_R - 2\delta + (1-\delta^2)\phi_R \cdot \frac{\alpha\rho(2S_k-1)}{\sigma(\rho+g)}\right]. \quad (20)$$

In contrast with Martin and Ottaviano (1999), the distribution of firms in our model also depends on the trade cost of the natural resource that represents the heterogeneous geographical distribution of the resource.

Thus far, we have obtained two equations, (16) and (20), 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 (16) is linear and increasing: given the local nature of the technological spillovers, the greater the concentration of firms, the lower the costs of innovation and the higher the growth rate. The function (20) is convex and decreasing[7]. 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

[7] The DME function (Equation 20) is convex and decreasing as long as $(\phi_R - \delta) > 0$. This condition is verified if $\tau_R \le \tau$, 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.

In our framework, an increase in the growth rate of the economy can come from different sources. Let us focus on three of them, highlighted in the last years in the empirical literature[8]: 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 economic growth and the use of the natural resource.

Apart from the direct effects of some variables that can be easily derived from (12) and (13), any variation in the distribution of firms and/or in the economic growth rate will also change the stock of the resource in the steady state. Note that both the harvest level in (12) and the stock of the resource in equilibrium in (13) depend on the aggregate world income $L\left(E + E^{*}\right)$. By combining (6), (8) and (14), such world income can be related to S_n and g:

$$L(E + E^{*}) = \frac{\eta\sigma(\rho + g)}{\alpha S_n}. \tag{21}$$

If we replace this expression in (12) and (13) we obtain:

$$R = \overline{R}\left[1 - \mu B \cdot \frac{(\sigma - 1)}{\gamma} \cdot \frac{\eta(\rho + g)}{S_n}\right], \tag{22}$$

$$H\left(R\right) = \mu BR \cdot (\sigma - 1) \cdot \frac{\eta(\rho + g)}{S_n}. \tag{23}$$

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

[8] A short review of this empirical literature is offered in the Introduction section.

An increase in population

Possibly the most important pressure on natural resources in our world is the 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 of goods, both the numeraire and any variety of the differentiated good (see Equations 8 and 9). 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 (12) 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 stronger competition among firms, which diminishes 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) for the increase in population in the aggregate world income $L\left(E + E^{*}\right)$. However, 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 (22) and (23), 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 use of the natural resource:

$$dR = -\overline{R}\mu B \cdot \frac{\alpha(\sigma - 1)}{\gamma\sigma} \cdot \left(E + E^{*}\right) dL < 0 .$$

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, new varieties are now developed at a faster rate and the whole economy grows faster, as Figure 2 shows. The influence of this 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 8 and 9). By substituting the growth rate (16) in the aggregate world income (21) we have $L(E+E^*) = 2L + \rho\frac{\eta}{S_n}$. Thus, for a given distribution of firms, the aggregate income falls, leading in the first instance 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 for 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:

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

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 for 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 (22), we obtain the effect of the reduction in transport costs on the stock of the natural resource in the steady state:

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

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

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

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

Welfare effects

Besides the effect on the stock of the natural resource, any of the changes considered above involve a reallocation of firms and a faster growth rate. A question that arises at this point is whether such change would be desirable from a welfare point of view. In order to try to answer this question, we analyse the indirect utility functions. Although it is difficult to carry out a rigorous analysis of welfare, given that any variation in the distribution of firms and the subsequent change in the growth rate have several different effects on the indirect utility function with the global sign remaining undetermined, we can identify the different effects that consumers would experience in utility. The indirect utility function of a household in the North is given by:

$$V = \frac{1}{\rho}\ln\left\{\alpha^{\alpha}(1-\alpha)^{1-\alpha}\left(\frac{\sigma-1}{\beta\sigma}\right)^{\alpha}\left(\frac{1}{p_R^{\mu}}\right)^{\alpha}\left(1+\frac{\rho\eta S_k}{S_n L}\right)N_0^{\frac{\alpha}{\sigma-1}}\left(S_n(\phi_R-\delta)+\delta\right)^{\frac{\alpha}{\sigma-1}}e^{\frac{\alpha g}{\rho(\sigma-1)}}\right\}. \quad (24)$$

Although the natural resource does not appear explicitly in consumer preferences (equation 1), it influences the indirect utility function indirectly through its price p_R. If we replace p_R from (11), the utility function becomes:

$$V = \frac{1}{\rho} ln\left\{ \alpha^{\alpha}(1-\alpha)^{1-\alpha}\left(\frac{\sigma-1}{\beta\sigma}\right)^{\alpha}(BR)^{\alpha\mu}\left(1+\frac{\rho\eta S_k}{S_n L}\right) N_0^{\frac{\alpha}{\sigma-1}}\left(S_n(\phi_R-\delta)+\delta\right)^{\frac{\alpha}{\sigma-1}} e^{\frac{\alpha g}{\rho(\sigma-1)}} \right\}. \quad (25)$$

For the sake of simplicity, let us consider an exogenous change in the concentration of firms.[9] By differentiating (25) we obtain:

$$\partial V = \left[-\frac{\eta S_k}{S_n^2 L + \rho\eta S_n S_k} + \frac{2L\alpha^2}{\rho^2\eta\sigma(\sigma-1)} + \frac{\alpha}{\rho(\sigma-1)} \cdot \frac{(\phi_R-\delta)}{(S_n(\phi_R-\delta)+\delta)} + \frac{\alpha^2\mu^2(\sigma-1)\overline{R}B\eta}{S_n^2\sigma\gamma R} \right] \partial S_n \gtrless 0$$

The effect on the welfare of a Northern household is undetermined. In addition to the three effects obtained by Martin and Ottaviano (1999), in our model a fourth effect deriving from the price of the natural resource arises, captured by the last term within the brackets. Thus, if the North manages to attract firms from the South, not only the economic growth rate and the steady state level of the stock of the resource will increase. Consumers in the North would also experience four effects on utility:

(1) The first element captures a negative impact on the wealth of Northern households. Since the concentration of firms in the North is raised, the cost of R&D decreases and the economic growth rate increases. This leads to a reduction in intermediate firms' monopolistic profits and, thus, *per capita* income decreases in the North.

(2) The second element represents the positive impact of a faster rate of introduction of new varieties of the intermediate good on the utility of individuals due to the 'love-of-variety' effect.

(3) The third term captures the increase in welfare due to decreasing trade costs for consumers in the North when S_n increases, since a lower range of varieties have to be imported. This effect depends on the differential $(\phi_R - \delta)$. It is easy to see that $(\phi_R - \delta) > 0$ as long as $\tau_R \le \tau$, as we assumed. Thus, a higher proportion of

[9] This analysis of utility is partial. In the concrete case that the cause of the variation in the concentration of firms were, for instance, a change in τ_R, additional effects would exist that would increase indeterminacy.

firms located in the North imply that Northern consumers will bear lower transport costs.

(4) The last element represents the positive effect of a higher concentration of firms in the North on the price of the natural resource. As the proportion of firms in the North increases, so does the stock of the natural resource in equilibrium, and this leads to a decrease in its price (equation 11). In turn, this decrease in the price of the input translates to the price of the differentiated goods, making consumers gain utility.

Similarly, the indirect utility function of a household in the South is:

$$V^* = \frac{1}{\rho} ln\left\{ \alpha^\alpha (1-\alpha)^{1-\alpha} \left(\frac{\sigma-1}{\beta\sigma}\right)^\alpha (BR)^{\alpha\mu} \left(1+\frac{\rho\eta(1-S_K)}{S_n L}\right) N_0^{\frac{\alpha}{\sigma-1}} \left(1-S_n(1-\phi_R\delta)\right)^{\frac{\alpha}{\sigma-1}} e^{\frac{\alpha g}{\rho(\sigma-1)}} \right\}.$$

(26)

And, by differentiating this function with respect to S_n, we obtain an analogous expression to that above:

$$\partial V^* = \left[-\frac{\eta(1-S_K)}{S_n^2 L + \rho\eta S_n(1-S_K)} + \frac{2L\alpha^2}{\rho^2\eta\sigma(\sigma-1)} - \frac{\alpha}{\rho(\sigma-1)} \cdot \frac{(1-\phi_R\delta)}{(1-S_n(1-\phi_R\delta))} + \frac{\alpha^2\mu^2(\sigma-1)\overline{R}B\eta}{S_n^2\sigma\gamma R} \right] \partial S_n \gtrless 0$$

with the difference being that the sign of the third effect is the opposite, since a higher concentration of firms in the North causes an increase in the transport costs borne by consumers in the South, so that their welfare decreases via prices.

In this situation, in which both the concentration of firms in the North and the economic growth rate increase, two positive effects on welfare are shared by the individuals of both countries: the ‘love-of-variety’ effect (a faster growth rate of the number of varieties), and the positive effect of the decreased price of the natural resource on the price of the differentiated goods. Nevertheless, the increase in the growth rate causes monopolistic profits of intermediate good producers to be reduced, and thus decrease the *per capita* income in both countries. However, as the Northern initial level of capital is higher, the income differential between North and South is reduced in relative terms (see equation 19).

7. Conclusions

The 20^{th} century involved a two-fold increase in the use of natural resources in per capita terms, as well as a 60% shortcut in the intensity of such resources per unit of GDP at a worldwide scale. This reveals that the more than eight-fold increase in the exploitation of the resources over the period was primarily driven by the growth in world population. The reduction in the intensity in the use of the resources, which indicates an important increase in productivity, has mitigated this process, and this paper has shown that the New Economic Geography provides insights about two elements that can curb the pressure on natural resources, namely the reduction in transports costs and a boost on the pace of innovation. These forces add to those used in favour of the Environmental Kuznets Curve; for instance, the change in the productive structure towards an increasing weighting of services, which are much less intensive in their use of natural resources than industry. Although these elements have been far from reversing the negative incidence of population growth on the environment over last century, their consequences deserve some attention.

To this aim, 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 spillovers in innovation, and the natural resource appears as a localized input subject to trade costs, which gives a cost advantage to firms located close to the resource. In such a framework, we discuss the relationship between economic growth and the evolution of the natural resources endowment at a global scale.

We consider three different sources of economic growth: an increase in population, a reduction in innovation costs and a reduction in the transport cost of the natural resource. In each of the three cases we obtain a faster economic growth rate, but the effect on the stock on the natural resource varies depending on the cause of the higher growth rate.

Demographic expansion is one element behind the increase in worldwide GDP, which is usually associated with the increasing exploitation of natural resources, even leading to a critical consumption of some of them. We confirm this result, supporting the consideration of population-driven economic growth as a threat to the environment.

However, we have found other elements that could mitigate this result once geographical issues are incorporated.

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 speeds up growth but, in parallel, favours a concentration of industry far from the natural resources area. Such reallocation reduces the natural resources demand.

The competition effect 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, again reduces the global demand for the resources. Thus, a faster innovation pace could coexist (in the absence of population growth) with a higher stock of natural resources.

These findings emphasize that the main threat on natural resources is not economic growth by itself, but the expansion of population at a global scale, particularly in developing countries. In these countries, relative poverty and lower access to family planning and education leads to high, sometimes even explosive, birth rates. Thus, programs for population control appear to be essential to avoid environmental damage. Taking apart the demographic challenge, our model suggests other policies to keep economic growth environmentally sustainable. On one hand, since growth driven by increases in productivity mitigates the pressure on inputs, policies must promote innovation and technological change by reducing the costs of R&D: subsidizing innovation or encouragement through tax incentives could be the more direct way, but also financing public basic research that favours applied R&D by firms. On the other hand, our results indicate that trade liberalization in natural resources, although increasing the demand due to the cheaper access to them, eventually leads to a lower use after the geographical reallocation of firms.

We are aware that these results rely on some theoretical assumptions that have enabled us to build the simplest possible model in analytical terms. On one hand, the particular characteristics of the natural resource considered, in particular that it is renewable and open access. 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 that could also influence the results, although the literature reveals that spatial issues, such as heterogeneity in production, can significantly alter efficient management of renewable natural resources (Costello and Kaffine, 2018).

On the other hand, we have considered homogeneous firms with the same technology and affected in the same way by economic growth. In an alternative framework with less and more advanced sectors (or 'dirty' and 'clean' technologies), the former more intensive in the use of natural resources and the latter more open to innovation, directed technical change would generate changes in relative prices that could lead to a reallocation of demand among products. In that case, the elasticity of substitution among the different products would appear as an additional determinant of the consequences in the use of the natural resource (Acemoglu et al., 2012).

Appendix A: Equilibrium conditions for the location of firms

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:

$$D_i = \frac{\sigma-1}{\beta\sigma} \cdot \frac{\left((\tau_R p_R)^{\mu}\right)^{-\sigma} \alpha E}{\left(n\left((\tau_R p_R)^{\mu}\right)^{1-\sigma} + n^* \delta \left(p_R^{\mu}\right)^{1-\sigma}\right)} \tag{A1}$$

$$D_j = \frac{\sigma-1}{\beta\sigma} \cdot \frac{\tau^{-\sigma} \left(p_R^{\mu}\right)^{-\sigma} \alpha E}{\left(n\left((\tau_R p_R)^{\mu}\right)^{1-\sigma} + n^* \delta \left(p_R^{\mu}\right)^{1-\sigma}\right)} \tag{A2}$$

$$Y = (1-\alpha)E \,. \tag{A3}$$

Equivalent expressions can be obtained for the demands of an individual in the South. These demands are similar to those obtained by Martin and Ottaviano (1999); the difference is that here the price of the natural resource (which depends inversely on the stock level) appears.

Four equations determine the location of firms in equilibrium and firms' size. First, total demand from both North and South for each variety (including transport costs) must equal supply. Thus, from (A1) and (A2):

$$x = \frac{\alpha L(\sigma-1)}{\beta\sigma} \cdot \left((\tau_R p_R)^{\mu}\right)^{-\sigma} \cdot$$

$$\cdot\left(\frac{E}{N\left(S_n\left((\tau_R p_R)^{\mu}\right)^{1-\sigma} + (1-S_n)\delta\left(p_R^{\mu}\right)^{1-\sigma}\right)} + \frac{\delta E^*}{N\left(S_n\delta\left((\tau_R p_R)^{\mu}\right)^{1-\sigma} + (1-S_n)\left(p_R^{\mu}\right)^{1-\sigma}\right)}\right) \tag{A4}$$

$$x^* = \frac{\alpha L(\sigma-1)}{\beta\sigma} \cdot \left(p_R^{\mu}\right)^{-\sigma} \cdot$$

$$\cdot\left(\frac{E^*}{N\left(S_n\delta\left((\tau_R p_R)^{\mu}\right)^{1-\sigma} + (1-S_n)\left(p_R^{\mu}\right)^{1-\sigma}\right)} + \frac{\delta E}{N\left(S_n\left((\tau_R p_R)^{\mu}\right)^{1-\sigma} + (1-S_n)\delta\left(p_R^{\mu}\right)^{1-\sigma}\right)}\right) \tag{A5}$$

The third condition is the equal retribution via profits of firms in both countries, as a consequence of the free capital movements between countries ($r = r^*$):

$$\pi = \pi^* . \tag{A6}$$

The fourth condition equals the total number of varieties to the worldwide supply of capital at each moment:

$$n + n^* = K + K^* = N . \tag{A7}$$

Solving this four-equation system we obtain equations (8) and (9).

Appendix B: 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 (16), and the North share in aggregate expenditure S_E in (19).

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Figure 1. Steady state equilibrium

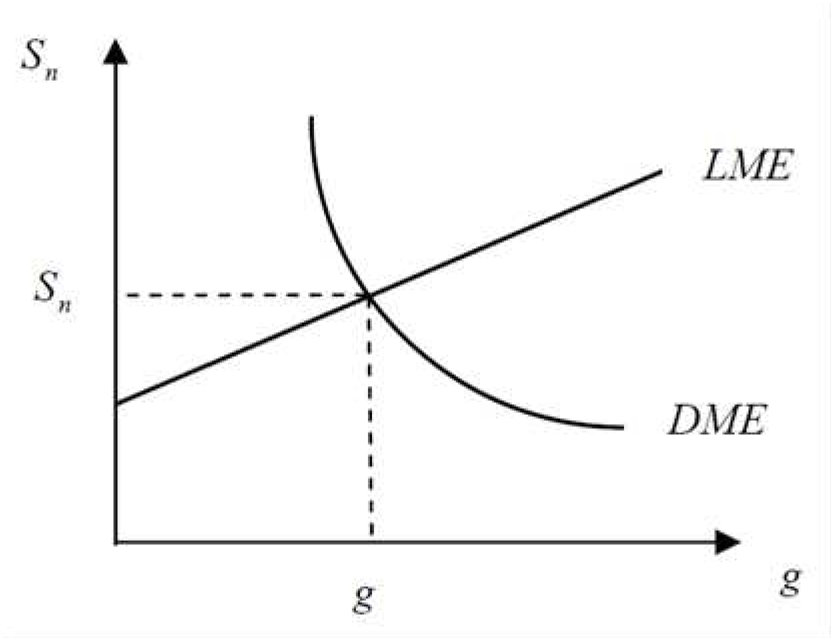

Figure 2. Effects of an increase in population or a reduction in innovation costs

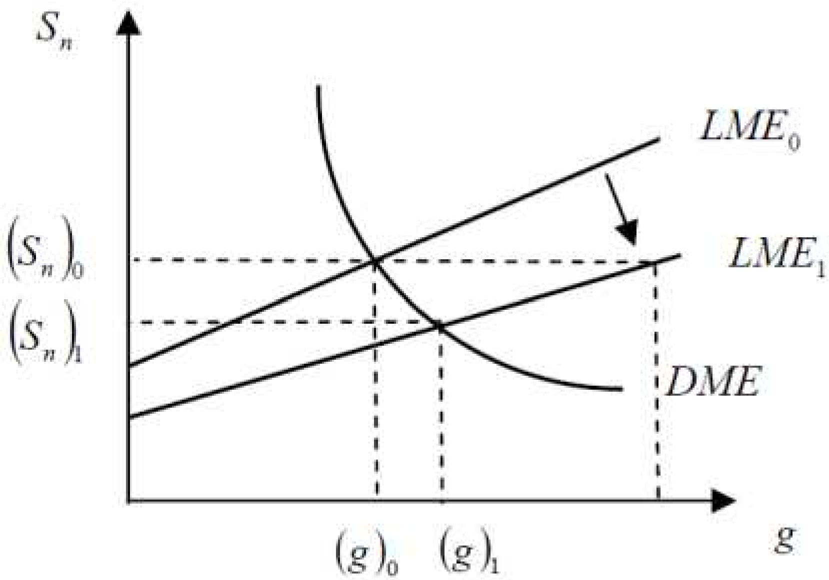

Figure 3. Effects of a reduction in the transport cost of the natural resource