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Resource windfalls, innovation, and growth

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This paper explores the connection between resource abundance and innovation, as a transmission mechanism that can elucidate part of the resource curse hypothesis, i.e. the observed negative impact of resource wealth on income growth. We develop a variation of the Ramsey-Cass-Koopmans model with endogenous growth to explain the phenomenon. In this model, consumers trade off leisure versus consumption, and firms trade off innovation efforts versus manufacturing. We show that an increase in resource income frustrates economic growth in two ways: directly by reducing work effort and indirectly by inducing a smaller proportion of the labor force to engage in innovation.

Keywords: natural resources; growth; innovation

JEL Classifications: O13, O51, Q33

1. Introduction

Directing work effort towards entrepreneurial activities is an important driving force of economic development. To some extent and in parallel, technological progress and improvements in labor productivity come as a by-product of other economic activities such as investment in educational quality or physical capital. In that respect, in the trade literature in particular, the link between learning-by-doing and the Dutch Disease has been explored in a number of papers. The main motivating idea (going back to Arrow 1962) assumes that as firms produce goods, they inevitably think of ways to improve their production techniques. Krugman (1987) assumes in his model that learning-by-doing (as a side effect of capital) occurs only in the traded sector. A discovery of tradeable natural resources will lead to an appreciation of the real exchange rate and a crowding out of other tradeable sectors. Such a shift of production of tradeable sectors from a home country abroad will result in declining relative home productivity. Similarly, Sachs and Warner (1995, 1999) assume that learning-by-doing (as a side effect of employment) takes place only in the traded sector. A resource boom in their model will drive labor away from the traded sector to the non-traded one and reduce the steady-state growth rate in the economy, since learning-by-doing takes place only in the traded sector. Torvik (2001) develops a model of learning-by-doing and the Dutch Disease assuming that learning-by-doing (as a side effect of labor) can occur in both the traded and the non-traded sector and that positive spillover effects between the two sectors may also take place (although weaker than the direct effects). In this way, the occurrence of Dutch

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Disease phenomena depends on the relative magnitude of learning-by-doing effects among sectors.

To a large extent, we learn to produce more efficiently by taking active steps in that direction. Booming primary sectors are likely to distort innovative activities in the economy and relocate entrepreneurial talent elsewhere. Individuals may prefer to become engaged in rent-seeking rather than productive activities, as described in Lane and Tornell (1996), Tornell and Lane (1999), Baland and Francois (2000), Torvik (2001) and Caselli and Cunningham (2009). They may even direct their skill and talent into parasitic activities such as warfare and robbery in order to improve their rent appropriation techniques (see Mehlum *et al.* 2003). In that respect, the crowding out of innovation or entrepreneurship is often neglected in the resource-curse literature. Sachs and Warner (2001) point out that wage premia in the resource sector may encourage innovators to engage in the primary rather than the R&D sector, but they do not further develop this idea. They claim that average weekly earnings in the oil industry may be more than twice the size of those in other manufacturing sectors in oil-producing countries such as Trinidad and Tobago. In Zambia, a labor aristocracy backed up by powerful trade unions preserved higher wages in the copper industry in the 1960s and 1970s (Burger 1974; Gupta 1974). The European Bank for Reconstruction and Development (EBRD) claims that the potential rent on Russian fossil fuels averaged 26% of GDP during 1992–2000, one third of which is estimated to have accrued to exporters (European Bank for Reconstruction and Development (EBRD) 2001).

In our model, the crowding-out effect of resource wealth on innovation and entrepreneurial activity is not an outcome of informal or illegal rent-seeking competition. It simply stems from formal possibilities of skilled employees to direct their work effort between alternative sectors. Furthermore, resource affluence does not only affect innovative activities by distorting the distribution of labor force among sectors, but also by encouraging individuals to work less intensively. Resource transfers reduce the need for labor income and increase the demand for leisure. For instance, it is highly likely that resource transfers in the form of unemployment benefits will discourage participation in the labor market. This rationale is consistent with the general tendency of resource-dependent countries to underutilize their factors of production (Gylfason 2001).

In Section 2, we develop a variation of the Ramsey-Cass-Koopmans model with endogenous growth, where individuals trade off consumption and leisure in terms of utility. Contrary to previous approaches (Krugman 1987; Matsuyama 1992; Torvik 2001) technological progress does not come as a side-effect (learning-by-doing) without resources being devoted to R&D activities. Innovation is the outcome of intentional actions rather than the by-product of other activities. The analysis is novel in that respect, since it attempts to elucidate how resource abundance may distort the incentives to engage into R&D production. Section 3 derives the dynamic equilibrium and main propositions linking resource abundance to innovation and economic performance. We show that an increase of the resource base in the economy induces a reduction in the steady-state labor supply. Resource rents allow individuals to reduce their work effort (and related disutility) and use the resource revenues to pay for extra consumption. Furthermore, we show that resource abundance affects growth indirectly by inducing a smaller proportion of the labor force to engage in innovation. Finally, Section 4 concludes.

Our formal analysis bears resemblance to recent work by Elíasson and Turnovsky (2004), who also examine the resource curse within an endogenous growth model. In both their and our approach, labor movements between sectors play an important role, but our study differs from their analysis with respect to the underlying mechanisms of economic growth. In their model, economic growth is based on increasing returns to scale in the manufacturing sector, due to capital spillover effects on labor productivity. A shift of labor and capital away from manufacturing towards the resource sector reduces the spillover effect and restricts economic expansion. In our model, we specify R&D explicitly through a third sector producing innovations, and this works as the engine of economic growth. The negative relationship between resource affluence and economic growth arises due to both a decrease in labor supply and a shift of labor away from R&D.

2. A model on resources and R&D

2.1. Consumers

In this section we analyze a Ramsey-Cass-Koopmans type of model, where infinitely-living households choose over time both the level of consumption and the share of time devoted to leisure in order to maximize their intertemporal utility. We also incorporate in our analysis an endogenous growth channel, where returns to technology investments (which can alternatively be conceived as knowledge or labor quality) depend positively on the level of labor input in the economy. The intuition is straightforward. Innovation and education become more productive when work effort increases. In other words, the harder we work, the more efficient, innovative and knowledgeable we become.

We assume that the economy consists of identical infinitely-lived agents. Population $N(t)$ remains constant at each point in time. Thus,

$$N(t) = N \tag{1}$$

For the type of model we employ, a stable population level is a convenient assumption that precludes an ever-increasing growth rate for income per capita and allows the economy to converge to a balanced growth path.

Individuals divide their available time between work and leisure. A proportion $l(t)$ of their time is devoted to work and the rest to leisure activities. Therefore, the level of labor input $L(t)$ in the economy is determined respectively by:

$$L(t) = l(t)N \tag{2}$$

Each representative household maximizes the following inter-temporal utility function:

$$U = \int_0^\infty u[c(t), l(t)]e^{-\rho t}\mathrm{d}t \tag{3}$$

where $c(t)$=$C(t)/N$ denotes consumption per person at time t, $C(t)$ stands for total consumption and ρ is the rate of time preference, which is assumed to be time-invariant and positive, implying that agents value future utility less comparatively to current utility. Thus, $U(t)$ is a weighted sum of all future discounted utility flows u[$c(t)$,$l(t)$], where u[$c(t)$,$l(t)$] represents the instantaneous utility function (also referred to as felicity function) of each agent at a given date.

We assume that the instantaneous utility function u[$c(t)$,$l(t)$] is separable with respect to its two arguments and depends positively on the consumption level $c(t)$ and negatively on work intensity $l(t)$. Thus, we assume that there is a disutility of working effort, or in other words, that agents obtain satisfaction from leisure activities. For convenience, we assume a logarithmic consumption utility function and a labor disutility function with constant elasticity σ. Furthermore, we omit time references for the rest of the analysis, unless there is need for clarification. Utility's functional form is now:

$$u(c, l) = \ln c - l^{1+\sigma} \tag{4}$$

Each household faces the following budget constraint when maximizing utility:

$$\dot{v} = wl + \frac{Q}{N} + rv - c \tag{5}$$

where $v=V/N$ stands for total value of assets hold per person, the dot denotes the derivative over time, wl and Q/N stand for wage and resource income per person, and r for the real interest rate obtained per unit of asset value. Each household, thus, maximizes utility subject to the budget constraint of Equation (5). Therefore, we set up the following Hamiltonian:

$$H = \int_0^\infty (\ln c - l^{1+\sigma})e^{-\rho t} + \mu[wl + \frac{Q}{N} + rv - c] \tag{6}$$

The first-order conditions with respect to the control variables c and l and the dual variable μ lead to the Ramsey Rule (7) and Equation (8), which describe the evolution of consumption over time and the substitution possibilities between consumption and leisure respectively:

$$\frac{\dot{c}}{c} = r - \rho \tag{7}$$

$$(1 + \sigma)l^\sigma / c = w \tag{8}$$

2.2. Producers

It is assumed that there are four sectors in our economy. First, there is a manufacturing sector with constant returns to scale with respect to its inputs labor and intermediates. The price of the final good produced in the manufacturing sector is normalized to unity. Following Romer (1990), we adopt the conventional specification of a continuum of intermediate capital goods, indexed by $i \in [0, A]$. Each intermediate capital good i represents a distinctive design, and the amount of designs A measures the total stock of knowledge. All designs are imperfect substitutes, whose level of substitution is captured by a parameter $0<\alpha<1$. Together, this leads to the following Cobb-Douglas production function for the manufacturing sector:

$$Y_M = (\gamma L)^{1-\alpha} \int_0^A x_i^\alpha \mathrm{d}i \tag{9}$$

where $0<\gamma<1$ is the share of laborers working in the manufacturing sector, and x_i is the input of capital of type i.

Firms in the manufacturing sector produce competitively and choose the level of labor and intermediate capital goods that maximize their profits:

$$\max_{\gamma L, x_i} (\gamma L)^{1-\alpha} \int_0^A x_i^\alpha \mathrm{d}i - w\gamma L - \int_0^A p_i x_i \mathrm{d}i \tag{10}$$

where w and p_i denote the labor wage (in the manufacturing sector) and the price of durable good i, respectively. The first-order conditions imply that each firm in the manufacturing sector faces the following demand equations for labor and durable goods:

$$w = (1-\alpha)(\gamma L)^{-\alpha} \int_0^A x_i^\alpha \mathrm{d}i = \frac{(1-\alpha)Y_M}{\gamma L} \tag{11}$$

$$p_i = \alpha(\gamma L)^{1-\alpha} x_i^{\alpha-1} \tag{12}$$

The first-order conditions, given by Equations (11) and (12), illustrate that firms pay labor and capital the value of their marginal products.

Secondly, there is a capital goods sector, where all capital intermediates are produced. Every durable good x_i is produced by a unique firm using a distinct patent (idea). This implies that all manufacturers of intermediate goods can exert monopolistic power, since their goods are imperfect substitutes, whose characteristics are determined by a specific design. Patent and copyright laws allow the specific firm that purchases and owns the design to use exclusively the corresponding idea and produce the related intermediate good. After incurring the fixed cost of innovation or the design purchase, each firm in the intermediate sector produces each durable good proportional to its capital input. In this way, intermediates can also be understood as durables, implying that $K = \int_0^A x_i \mathrm{d}i$, where K is a measure of the total capital stock.

Firms producing in the intermediate-goods sector buy the ownership for a design at price P_A, and after incurring the fixed cost of the design purchase, maximize profits π:

$$\max_{x_i} \pi_i = p_i(x_i)x_i - rx_i \tag{13}$$

where $p_i(x_i)$ is the demand function for each durable good from the side of the manufacturing sector firms, as shown in Equation (12). Therefore, $p_i(x_i)x_i$ equals the revenues of each firm operating in the intermediate-goods sector. The second part of the maximization represents the interest cost firms face when producing each durable good x_i. As stated above, each firm in the intermediate sector transforms one unit of raw capital into one unit of intermediate good. The first-order condition with respect to x_i provides us with:

$$\frac{\mathrm{d}p_i(x_i)}{\mathrm{d}x_i} x_i + p_i(x_i) = r$$

and after taking account of the demand function for durables, Equation (12), we can see that the monopoly price of each durable good is a mark-up over marginal cost that is equal for every design:

$$p_i = p = r/\alpha \tag{14}$$

As Equation (14) reveals, all intermediate capital goods sell at the same price. Since the demand function (12) refers to each individual intermediate good produced, Equation (14) implies that each durable good is purchased and employed by the manufacturing sector by the same amount x. Therefore, we have:

$$K = \int_0^A x_i \mathrm{d}i = Ax \tag{15}$$

The profits make the ownership of a design a valuable asset with price P_A and, as such, they constitute a return to this asset value:

$$rP_A = \pi + \dot{P}_A \tag{16}$$

On a balanced growth path, Equation (16) simplifies to $rP_A = \pi$.

Third, we assume an R&D sector where designs for new intermediate goods are produced as in Romer (1990). This sector adds to the knowledge base. It employs a fraction $1–\gamma$ of the labor input, which is the remainder of the labor force not employed in the manufacturing sector. The production function of knowledge has constant returns to scale with respect to labor. This specification abstracts from duplication of effort; nor is there a positive spillover between researchers in the R&D sector. Furthermore, the production of designs depends positively on the stock of knowledge already discovered on a one-to-one base. This implies that the growth rate of innovation (the rate of design accumulation) is independent of the level of knowledge. The stock of knowledge is freely available to all researchers in the R&D sector as a public good, and this fosters innovation. Thus, designs evolve according to:

$$\dot{A} = A(1 - \gamma)L \tag{17}$$

Knowledge is produced in the innovation sector, where labor earns its marginal value. Every design invented is sold to a firm in the intermediate-goods sector for a price P_A. Marginal productivity of labor in the innovation sector thus becomes:

$$w = AP_A \tag{18}$$

Last, we assume there is a resource sector exploiting the natural resource endowment of the economy (e.g. oil reserves, mines, fishing banks, timber etc). The production of the resource sector Q depends on the resource endowment available G (for instance the oil reserves discovered or the stock of fish) and the stock of physical capital K. The first component is apparent. The larger the resource base available, the larger is the potential to process and exploit the resource endowment. Resource booms make a larger amount of natural resources available for the resource sector to be exploited. The second component assumes that as a side effect of capital accumulation, natural resources are exploited more effectively. We take the simple proportional production function,

$$Q(K, G) = GK \tag{19}$$

2.3. Closure

The production function for the manufacturing sector, after taking account of the capital-intermediate identity, equation (15), becomes:

$$Y_M = (\gamma L)^{1-\alpha} A x^a = (A\gamma L)^{1-\alpha} K^\alpha \tag{20}$$

Equation (20) reveals that production in manufacturing resembles the neoclassical Solow model. The commodity flows are closed by setting total output, or income Y, from the manufacturing and resource sectors, equal to consumption C plus capital accumulation $\dot{K}$:

$$Y = (A\gamma L)^{1-\alpha} K^a + KG = C + \dot{K} \tag{21}$$

3. Analysis

3.1. Dynamic equilibrium

In this sub-section, we determine the equations governing the dynamics for consumption, the capital stock, labor supply and the share of labor involved in innovation.

First, we determine the share of labor employed in the manufacturing sector versus the innovation sector. We compare wages for labor employed in the innovation sector and manufacturing sector, and the rate of returns to the two assets, knowledge A and capital K. Labor arbitrage between the manufacturing and innovation sector ensures equal wages. Thus, Equation (11) and (18) make:

$$AP_A = \frac{(1-\alpha)Y_M}{\gamma L} \tag{22}$$

Next, we determine the level of the interest rate r for capital K. From the demand function (14), we know that the interest rate is the product of the parameter α and the durables price p. After substituting for the price p from Equation (12), the amount of each durable demanded and produced x from Equation (15) and taking account of the production function in the manufacturing sector, Equation (9), we know that the level of interest rate r is proportional to the ratio of the manufactured output to capital:

$$r = \alpha^2 \frac{Y_M}{K} \tag{23}$$

We then proceed to calculate the interest earned on knowledge.

The immediate profits of each firm in the intermediate-goods sector are calculated by incorporating Equations (12), (14) and (15) into (13):

$$\pi_i = \pi = \alpha(1-\alpha)(\gamma L)^{1-\alpha} x^\alpha = \alpha(1-\alpha)\frac{Y_M}{A} \tag{24}$$

Taking account of Equations (24) and (16) determining the price of patents P_A and the level of monopolistic profits π, in balanced growth, Equation (22) becomes:

$$r = \alpha\gamma L \tag{25}$$

After incorporating Equation (23) into Equation (25), we can express the share of the labor input engaged into the manufacturing sector in terms of the ratio of output (in manufacturing) to capital:

$$\gamma = \frac{\alpha}{L}\frac{Y_M}{K} = \frac{\alpha}{lN}\frac{Y_M}{K} \tag{26}$$

For the analysis of dynamics, it is useful to write equations in intensive form. From Equation (21), we can derive the intensive form of total income in the economy by dividing the left-hand-side by labor in effective terms AL:

$$\hat{y} = \gamma^{1-\alpha}\hat{k}^{1-\alpha} + G\hat{k} \tag{27}$$

where lower letter variables with hats denote variables expressed relative to effective labor supply, $\hat{y} = Y/AL$, $\hat{k} = K/AL$, $\hat{c} = C/AL$.

Substituting for the output in the manufacturing sector from Equation (20) into Equation (23) allows us to express the interest rate in terms of capital per effective labor,

$$r = \alpha^2\hat{k}^{\alpha-1}\gamma^{1-\alpha} \tag{28}$$

and the share of laborers in the manufacturing sector from Equation (26) as

$$\gamma = (\frac{\alpha}{lN})^{\frac{1}{\alpha}}\hat{k}^{\frac{\alpha-1}{\alpha}} \tag{29}$$

We rewrite Equation (7) in its intensive form, and substitute Equations (17) and (28):

$$\frac{\dot{\hat{c}}}{\hat{c}} = r - \rho - \frac{\dot{A}}{A} - \frac{\dot{l}}{l} = \alpha^2\hat{k}^{\alpha-1}\gamma^{1-\alpha} - \rho - (1-\gamma)lN - \frac{\dot{l}}{l} \tag{30}$$

Subsequently, we rewrite Equation (21) in its intensive form substituting (27):

$$\frac{\dot{\hat{k}}}{\hat{k}} = \gamma^{1-\alpha}\hat{k}^{\alpha-1} + G - \frac{\hat{c}}{\hat{k}} - \frac{\dot{l}}{l} - (1-\gamma)lN \tag{31}$$

These two equations show that consumption and capital dynamics depend on labor supply dynamics. To solve for $\dot{l}/l$, we first express the level of labor wage in terms of capital per labor k. From Equations (11) and (20), we can calculate:

$$w = (1–\alpha)k^{\alpha}\gamma^{-\alpha}A^{1-\alpha} \tag{32}$$

Combining Equations (8) and (32) provides us with the following equation:

$$(1+\sigma)l^{\sigma}c = (1–\alpha)k^{\alpha}\gamma^{-\alpha}A^{1-\alpha} \tag{33}$$

which can be expressed in terms of effective labor as:

$$(1+\sigma)l^{1+\sigma}\hat{c} = (1-\alpha)\hat{k}^{\alpha}\gamma^{-\alpha} \tag{34}$$

Together, we have four equations that determine the dynamics of $\hat{c}$, Equation (30), $\hat{k}$ Equation (31), and the levels of γ, Equation (29) and l, Equation (34). For use in the steady state analysis, we also derive equations that describe the labor supply l and use γ dynamics. Equation (34) implies that l evolves according to:

$$\frac{\dot{l}}{l} = \frac{\alpha}{1+\sigma}\frac{\dot{\hat{k}}}{\hat{k}} - \frac{1}{1+\sigma}\frac{\dot{\hat{c}}}{\hat{c}} - \frac{\alpha}{1+\sigma}\frac{\dot{\gamma}}{\gamma} \tag{35}$$

From Equation (29) we see that γ evolves according to:

$$\frac{\dot{\gamma}}{\gamma}=\frac{\alpha-1}{\alpha}\frac{\dot{\hat{k}}}{\hat{k}}-\frac{1}{\alpha}\frac{\dot{l}}{l} \tag{36}$$

Combining Equations (35) and (36), we see that l evolves according to:

$$\frac{\dot{l}}{l}=\frac{1}{\sigma}\left(\frac{\dot{\hat{k}}}{\hat{k}}-\frac{\dot{\hat{c}}}{\hat{c}}\right) \tag{37}$$

3.2. Steady state

Along a balanced growth path, capital K, consumption C, output Y and technology A grow at the same rate, which implies that the levels of $\hat{k}$, $\hat{c}$ and $\hat{y}$ remain constant along the path. It can be seen from Equations (36) and (37) that the working intensity l and the labor input share γ remain constant as well. Therefore, along the balanced growth path Equations (30) and (31) become:

$$\alpha^2\hat{k}_s^{\alpha-1}\gamma_s^{1-\alpha}-\rho-(1-\gamma_s)l_sN=0 \tag{38}$$

$$\gamma_s^{1-\alpha}\hat{k}_s^{\alpha-1}+G-\frac{\hat{c}_s}{\hat{k}_s}-(1-\gamma_s)l_sN=0 \tag{39}$$

where the subscript S denotes the steady-state value of each variable along the balanced growth path.

Equations (29) and (34), evaluated at the steady-state, give the following levels of labor supply l and the share of laborers employed in innovation,

$$\gamma_s=\left(\frac{\alpha}{l_sN}\right)^{\frac{1}{\alpha}}\hat{k}_s^{\frac{\alpha-1}{\alpha}}=\left(\frac{\alpha}{N}\right)^{\frac{1}{\alpha}}l_s^{-\frac{1}{\alpha}}\hat{k}_s^{\frac{\alpha-1}{\alpha}} \tag{40}$$

$$(1+\sigma)l_s^{1+\sigma}\hat{c}_s=(1-\alpha)\hat{k}_s^{\alpha}\gamma_s^{-\alpha} \tag{41}$$

Along with Equations (38) and (39), these two equations constitute a system of four equations depending on the four steady-state levels $\hat{k}_s$, $\hat{c}_s$, l_s and γ_s. Substitution of these four equations produces a single equation linking resource income to labor supply l_s:

$$G=\rho\frac{1+\alpha}{1+\alpha N}\frac{N}{\alpha}+\frac{1-\alpha}{1+\sigma}\frac{N}{\alpha}l_s^{-\sigma}-\frac{1+\alpha}{1+\alpha N}\frac{N^2}{\alpha}(1-\alpha)l_s \tag{42}$$

The right-hand-side of Equation (42) is strictly decreasing in labor supply, l_s, so that there is only one unique steady-state value, and we can derive that

$$\frac{\mathrm{d}l_s}{\mathrm{d}G}=\left[-\sigma\frac{1-\alpha}{1+\sigma}\frac{N}{\alpha}l_s^{-1-\sigma}-\frac{1+\alpha}{1+\alpha N}\frac{N^2}{\alpha}(1-\alpha)\right]^{-1}<0$$

This shows that an increase in resource abundance as captured by G results in a decrease of labor intensity at the steady state. Individuals trade off consumption and leisure in terms of utility. An increased amount of resource wealth gives them the opportunity to enjoy the same level of utility for a reduced labor effort. In other words, resource abundance increases leisure and reduces man-made output. We state this finding as the first proposition:

Proposition 1. *The steady state level of labor supply l_s is decreasing in the resource base G.*

The rate of knowledge accumulation at the steady-state is given by equation (17). We label the steady state rate of knowledge accumulation by $\chi_s = (\dot{A}_s/A_s)$,

$$\chi_s = (1 - \gamma_s) l_s N \tag{44}$$

From Equations (40) and (A5), in the Appendix, we derive the ratio of the labor force engaged in the R&D sector $(1 - \gamma_s)$:

$$1 - \gamma_s = 1 - \frac{N + \rho l_s^{-1}}{1 + \alpha N} \tag{45}$$

Equation (45) implies that a decrease in labor intensity at the steady-state due to an increase in resource endowments, as indicated by Equation (43), decreases the ratio of the labor force engaged in the R&D sector. Therefore, the accumulation of knowledge decreases for two reasons. First, the reduction in labor intensity directly retards knowledge accumulation. Secondly, the decrease in labor intensity reduces the rate of knowledge accumulation indirectly by lowering the percentage of the labor force engaged in the R&D sector. From Equation (44), we see that technological progress depends negatively on the level of resource endowment (both directly and indirectly):

$$\frac{\mathrm{d}\chi_s}{\mathrm{d}G} = \left[(1 - \gamma_s)N + \frac{\rho}{(1 + \alpha N) l_s}\right] \frac{\mathrm{d}l_s}{\mathrm{d}G} < 0 \tag{46}$$

where the derivative $\frac{\mathrm{d}l_s}{\mathrm{d}G}$ is negative from equation (43).

Therefore, a resource-abundant country with a large natural resource base G will experience a lower labor intensity l_s at the steady state and a lower rate of knowledge accumulation χ_s. The economy will grow at a slower pace. Thus, Proposition 2 is our major finding.

Proposition 2. *Steady state R&D effort and implied economic growth χ_s is decreasing in the resource base G.*

4. Conclusion

Technological progress is one of the main driving forces behind economic growth, and as such it deserves particular attention. Countries grow faster over time, as they invest in projects that improve their productivity of capital and labor. Directing work effort towards R&D activities is an obvious way to support productivity growth. In that direction, it is of particular interest to explore the resource curse hypothesis within an endogenous growth perspective.

In this section, we investigate a resource curse mechanism not extensively discussed in the literature: the relationship between resource abundance and innovation. The pursuit by innovators of new ideas and designs is motivated by their interest in profiting from them. In our model, natural resources reduce the incentives of innovators to engage in R&D. This happens for two reasons. First, the discovery of resource reserves reduces the need to support consumption through labor income and therefore increases leisure and reduces work effort. Secondly, resource wealth negatively affects the allocation of entrepreneurial activity between the manufacturing and the R&D sector in favor of the former.

Extensions of the analysis should take into account the possibility that work effort may also be allocated in the primary sector, as suggested by Sachs and Warner (2001). In this case, the share of the labor force employed as researchers in the R&D sector will be directly affected by the amount of resource rents, rather than indirectly (through labor intensity) as happens in our model. Furthermore, a more extensive database should allow us to disentangle the effect of natural resources into more specific consequences of its components. It is possible that specific categories of natural resources, such as minerals and ores have stronger (or weaker) crowding-out effect on innovation than others. Additionally, we believe that as soon as there is a collection of reliable data on innovation for a large number of countries (especially developing ones), it will be particularly promising to identify a similar growth-frustrating mechanism of resource abundance across countries.

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References

Arrow, K.J., 1962. The economic implications of learning-by-doing. *Review of Economic Studies,* 29 (3), 155–173.

Baland, J.-M., and Francois, P., 2000. Rent-seeking and resource booms. *Journal of Development Economics,* 61 (2), 527–542.

Burger, E.L., 1974. *Labor, race, and colonial rule: The Copperbelt from 1924 to independence*. Oxford: Clarendon Press.

Caselli, F., and Cunningham, T., 2009. Leader behaviour and the natural resource curse. *Oxford Economic Papers,* 61 (4), 628–650.

Elíasson, L., and Turnovsky, S.J., 2004. Renewable resources in an endogenously growing economy: balanced growth and transitional dynamics. *Journal of Environmental Economics and Management,* 48 (3), 1018–1049.

European Bank for Reconstruction and Development (EBRD), 2001. *Transition report 2001: energy in transition*. London.

Gupta, A., 1974. Trade unionism and politics on the Copperbelt. *In*: W. Tordoff, ed. *Politics in Zambia*. Manchester: University Press.

Gylfason, T., 2001. Natural resources, education, and economic development. *European Economic Review,* 45 (4–6), 847–859.

Krugman, P., 1987. The narrow moving band, the Dutch Disease and the competitive consequences of Mrs Thatcher. *Journal of Development Economics,* 27 (1–2), 41–55.

Lane, P.R., and Tornell, A., 1996. Power, growth, and the voracity effect. *Journal of Economic Growth,* 1 (2), 213–241.

Matsuyama, K., 1992. Agricultural productivity, comparative advantage, and economic growth. *Journal of Economic Theory,* 58 (2), 317–334.

Mehlum, H., Moene, K., and Torvik, R., 2003. Destructive creativity. *Nordic Journal of Political Economy,* 29 (1), 77–83.

Romer, P.M., 1990. Endogenous technological change. *Journal of Political Economy,* 98 (5), 71–102.

Sachs, J.D., and Warner, A.M., 1995. Natural resource abundance and economic growth, NBER Working Paper No 5398. Cambridge, MA: National Bureau of Economic Research.

Sachs, J.D., and Warner, A.M., 1999. Natural resource intensity and economic growth. *In*: J. Mayer, B. Chambers and F. Ayisha, eds. *Development policies in natural resource economics*. Cheltenham: Edward Elgar.

Sachs, J.D., and Warner, A.M., 2001. Natural resources and economic development: the curse of natural resources. *European Economic Review,* 45 (4–6), 827–838.

Tornell, A., and Lane, P.R., 1999. The voracity effect. *American Economic Review,* 89 (1), 22–46.

Torvik, R., 2001. Learning by doing and the Dutch Disease. *European Economic Review,* 45 (2), 285–306.

Appendix. Derivation of steady-state dynamics

Incorporating Equation (40) into Equations (38), (39) and (41) yields:

$$l_s^{\frac{\alpha-1}{\alpha}}\hat{k}_s^{\frac{\alpha-1}{\alpha}}(\frac{\alpha}{N})^{\frac{1}{\alpha}}(1+\alpha N)-\rho-l_sN=0 \tag{A1}$$

$$l_s^{\frac{\alpha-1}{\alpha}}\hat{k}_s^{\frac{\alpha-1}{\alpha}}(\frac{\alpha}{N})^{\frac{1-\alpha}{\alpha}}(1+\alpha)+G-\frac{\hat{c}_s}{\hat{k}_s}-l_sN=0 \tag{A2}$$

and

$$\hat{c}_s=\frac{N(1-\alpha)}{\alpha(1+\sigma)}l_s^{-\sigma}\hat{k}_s \tag{A3}$$

Incorporating Equation (A3) into Equation (A2) yields:

$$l_s^{\frac{\alpha-1}{\alpha}}\hat{k}_s^{\frac{\alpha-1}{\alpha}}(\frac{\alpha}{N})^{\frac{1-\alpha}{\alpha}}(1+\alpha)+G-\frac{1-\alpha}{1+\sigma}(\frac{\alpha}{N})^{-1}l_s^{-\sigma}-l_sN=0 \tag{A4}$$

Rearranging Equation (A1) yields:

$$\hat{k}_s^{\frac{\alpha-1}{\alpha}}=(\rho+l_sN)(\frac{\alpha}{N})^{-\frac{1}{\alpha}}(1+\alpha N)^{-1}l_s^{\frac{1-\alpha}{\alpha}} \tag{A5}$$

Incorporating Equation (A5) into Equation (A4) solves for the steady-state value of labor intensity in Equation (42).