Natural Resources, Innovation, and Growth [a]

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ABSTRACT

This paper investigates 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. For this model, 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.

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1. INTRODUCTION

Recent empirical evidence and theoretical work provides strong support to a resource curse hypothesis; i.e. natural resource wealth tends to impede rather than promote economic growth (Auty 1994, Sachs and Warner 1995, 1997, 1999a, 1999b, Leite and Weidmann 1999, Rodriguez and Sachs 1999, Gylfason 2000, 2001a, 2001b, Papyrakis and Gerlagh 2004). The expectations of many early development economists (Nurkse 1953, Rostow 1960, Watkins 1963) that natural capital would be an important pillar to build economic development proved at odds with outcomes. Resource riches such as oil reserves, fish banks and fertile land became associated with a slowdown in economic growth across the world during the last three decades. One of the most striking examples and manifests of the resource curse hypothesis is the disappointing performance of the oil cartel countries. Over the last four decades, the OPEC countries as a whole experienced a negative rate of GDP per capita growth (Gylfason 2001b). Venezuela ranked among the ten wealthiest nations at the beginning of 19th century, but despite its vast oil reserves, it is downgraded to the level of a developing country (Jones 2002). Similarly, Alaska is the only U.S. state with a negative growth rate over the last two decades, despite its extensive oil reserves and fishing industry.

Several theories have been developed and tested to explain the resource curse paradox. The main focal point of these analyses lies in the crowding-out effects of resource wealth, as resource wealth decreases the perceived need for growth supporting policies, prudent long-term planning and efficient management of available resources (Ascher 1999, Auty 2001, Gylfason 2001b, Usui 1997). Resource abundance retards economic growth by crowding-out its determinants (Sachs and Warner 2001). Resource rich countries tend to suffer from

currency appreciations and loss of competitivess (Corden 1984), inefficient allocations of resources (Corden and Neary 1982, Robinson and Torvik 2004), enhanced corruption and rent-seeking (Baland and Francois 2000, Krueger 1974, Torvik 2002), bad-decision making (Sachs and Warner 1999b, Auty 2001), increased public spending (Ross 2001) and political instability (Collier and Hoeffler, 1998, Olsson 2003).

The scope of this paper is on a crowding out effect of resource abundance mostly neglected in the literature: the crowding out of innovation or entrepreneurship. 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. But since technological progress and the discovery of new ideas and inventions drive long-term growth, we think the effect of natural resources on R&D deserves our attention. 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. 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.

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 plays 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. The advantage of our explicit recognition of R&D is that we can test our model empirically, using cross-US state data on natural resource abundance, R&D expenditures, and economic growth. Specifically, we estimate the magnitude of the crowding-out effect of resource abundance on R&D, and its indirect impact on economic growth.

Section 4 backs up the formal analysis by an extensive statistical analysis linking natural resources, R&D expenditures and growth for US states. Our choice for US states is based on data availability for R&D expenditures. Moreover, a merit of our sample choice is that whereas countries often differ in dimensions – such as language, the quality of institutions and cultural characteristics – that are difficult to control for in growth regressions, these differences are likely to be smaller across regions within a country (Barro and Sala-i-Martin 1995). The U.S. are a relatively homogeneous country, compared to cross-country analyses, and therefore, a regional U.S. analysis may provide more precise estimates of the effect of resource wealth on growth and the R&D channel through which this can take place. Finally, Section 5 concludes.

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:

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

where $c(t)=C(t)/N$ denotes consumption per person at time t, $C(t)$ stands for total consumption, ρ is the rate of time preference and it 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 the work intensity $l(t)$. In other words, we assume that there is a disutility of working effort and agents obtain satisfaction from leisure activities. For convenience, we assume a logarithmic consumption utility function and a labor disutility function with constant elasticity σ. Also, we omit any time references for the rest of the analysis, unless there is need for clarification.

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

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:

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

(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:

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

(7)

$$(1+\sigma)l^\sigma/c = w$$

(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, the level of substitution captured by a parameter $0<\alpha<1$. Together, this leads to the following Cobb-Douglas production function for the manufacturing sector:

$$Y_M = (\gamma L)^{1-\alpha} \int_0^A x_i^\alpha \, di \,, \tag{9}$$

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:

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

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 for labor and durable goods:

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

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

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 distinct 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 are allowing 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 $K = \int_0^A x_i di$, 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:

$$\frac{dp_i(x_i)}{dx_i} x_i + p_i(x_i) = r,$$

and after taking account of the demand function for durables (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:

$$K = \int_0^A x_i di = Ax \tag{15}$$

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, the equation 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:

$$\dot{A} = A(1-\gamma)L.$$
(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:

$$w = AP_A.$$
(18)

Last, we assume there is a resource sector exploiting the natural resource endowments 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 obvious. 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,

$$Q(K, G) = GK.$$
(19)

2.3. Closure

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

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

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 $\dot{K}$:

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

3. ANALYSIS

3.1. Dynamic Equilibrium

In this sub-section, we determine the equations that govern 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 innovations 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 (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 (12), the amount of each durable demanded and produced x from (15) and taking account of the production function in the manufacturing sector (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 can be 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 (25), we can express the share of the labor input engaged into the manufacturing sector in terms of the ratio of the 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 forms. 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 :

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

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

Substituting for the output in the manufacturing sector from equation (20) into (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 (26) as

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

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

$$\frac{\overset{\wedge}{\overset{\bullet}{c}}}{\hat{c}} = r - \rho - \frac{\overset{\bullet}{A}}{A} - \frac{\overset{\bullet}{l}}{l} = \alpha^2 \hat{k}^{\alpha-1} \gamma^{1-\alpha} - \rho - (1-\gamma)lN - \frac{\overset{\bullet}{l}}{l} \qquad (30)$$

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

$$\frac{\overset{\wedge}{\overset{\bullet}{k}}}{\hat{k}} = \gamma^{1-\alpha} \hat{k}^{\alpha-1} + G - \frac{\hat{c}}{\hat{k}} - \frac{\overset{\bullet}{l}}{l} - (1-\gamma)lN . \qquad (31)$$

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

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

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

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

which can be expressed in terms of effective labor as:

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

Together, we have four equations that determine the dynamics for $\hat{c}$ (30), $\hat{k}$ (31), and the levels of γ (29) and l (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 can 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:

$$\alpha^2 \hat{k}_{ss}^{\alpha-1} \gamma_{ss}^{1-\alpha} - \rho - (1-\gamma_{ss})l_{ss}N = 0 \tag{38}$$

$$\gamma_{ss}^{1-\alpha} \hat{k}_{ss}^{\alpha-1} + G - \frac{\hat{c}_{ss}}{\hat{k}_{ss}} - (1-\gamma_{ss})l_{ss}N = 0, \tag{39}$$

where the subscript *SS* 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 for labor supply *l* and the share of laborers employed in innovation,

$$(1+\sigma)l_{ss}^{1+\sigma}\hat{c}_{ss} = (1-\alpha)\hat{k}_{ss}^{\alpha}\gamma_{ss}^{-\alpha}, \tag{40}$$

$$\gamma = \left(\frac{\alpha}{l_{ss}N}\right)^{\frac{1}{\alpha}}\hat{k}_{ss}^{\frac{\alpha-1}{\alpha}} = \left(\frac{\alpha}{N}\right)^{\frac{1}{\alpha}}l_{ss}^{-\frac{1}{\alpha}}\hat{k}_{ss}^{\frac{\alpha-1}{\alpha}}. \tag{41}$$

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

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

The right-hand-side of equation (42) is strictly decreasing in labor supply, l_{ss}, so that there is only one steady-state value, and we can derive that

$$\frac{dl_{ss}}{dG} = \left[-\sigma\frac{1-\alpha}{1+\sigma}\frac{N}{\alpha}l_{ss}^{-1-\sigma} - \frac{1+\alpha}{1+\alpha N}\frac{N^2}{\alpha}(1-\alpha)\right]^{-1} < 0 \tag{43}$$

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_{ss} 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 $\chi_{ss} = (\dot{A}_{ss} / A_{ss})$,

$$\chi_{ss} = (1 - \gamma_{ss}) l_{ss} N \tag{44}$$

From equations (41) and (54), in the appendix, we derive the ratio of the labor force engaged in the R&D sector $(1 - \gamma_{ss})$:

$$1 - \gamma_{ss} = 1 - \frac{N + \rho l_{ss}^{-1}}{1 + \alpha N} \tag{45}$$

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 can see that technological progress depends negatively on the level of resource endowments (both directly and indirectly):

$$\frac{d\chi_{ss}}{dG} = \left[(1-\gamma_{ss})N + \frac{\rho}{(1+\alpha N)l_{ss}}\right]\frac{dl_{ss}}{dG} < 0, \tag{46}$$

where the derivative $\dfrac{dl_{ss}}{dG}$ is negative from equation (43).

Therefore, a resource-abundant country with a large natural resource base G will experience a lower labor intensity l_{ss} at the steady state and a lower rate of knowledge accumulation χ_{ss}. The economy will grow at a slower pace. This is our major finding:

PROPOSITION 2. *Steady state economic growth χ_{ss} is decreasing in the resource base G.*

4. US EMPIRICAL EVIDENCE

In this section we provide empirical evidence for the negative relationship between resource-abundance and innovation and its consequent impact, thereof, on economic growth. First, for 49 U.S. states,[1] we estimate the effect of natural resource abundance on R&D efforts. We use the share of the primary sector's production (agriculture, forestry, fishing and mining) in Gross State Product (GSP) –the state equivalent to GDP– in 1994, as a proxy for resource-abundance (*Nat*). As a measure of innovation we use the share of R&D expenditure in GSP for 1995 (*R&D*). We also include an extended innovation measure (*Innov*) to deal with cross-state spill-over effects of R&D. The new innovation variable is an equally weighted sum of each region's share of R&D expenditure in GSP for 1995 and the average share of the neighboring states:

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[1]   Data on innovation are unavailable for the District of Columbia and Delaware.

$Innov_i = \frac{1}{2} R \& D_i + \frac{1}{2} \sum_{j=0}^{n} \left(R \& D \right)_j$, where i represents the state of interest, and n the number of neighboring states and j the index of neighboring states. Data on GSP and natural resources are available by the Bureau of economic Analysis of the U.S. Ministry of Commerce, while data on innovation by the Industry, Research and Development System (IRIS) of the National Science Foundation (NSF) respectively.

We adopt the following specification of the dependence of the variables $R\&D$ and $Innovation$, generically written as Z^i, on resource income:

$$Z^i = \beta_0 + \beta_1 \ln(Y_0^i) + \beta_2\, Nat^i + \mu^i. \tag{47}$$

Table 1 lists the regressions of the two innovation proxies on resource abundance and initial income. The results indicate a strong and very significant negative correlation between resource abundance and innovation, even when controlling for initial income levels.

TABLE 1. *Innovation and Resource-Abundance.*

	R&D (1)	Innov (2)
Constant	−10.66	−10.66
$Ln\,Y_{94}$ (0.15)	2.02** (2.16)	1.22* (1.89)
Nat (0.06)	−8.00*** (−3.35)	−6.20*** (−3.74)
R^2 adjusted	0.21	0.23
N	49	49

Note: t-statistics for coefficients in parentheses. Superscripts *, **, *** correspond to a 10, 5 and 1% level of significance.

In order to justify that resource-dependent U.S. states had a comparative disadvantage in terms of income growth, and to evaluate the extent to which this may be attributed to lower innovation, we estimate cross-state growth regressions for 1994-2000 using OLS in the tradition of Kormendi and Meguire (1985), Grier and Tullock (1989), Barro (1991) and Sachs and Warner (1995, 1997). Thus, we assume that per capita economic growth, denoted by $G^i=(1/T)\ln(Y_T^i/Y_0^i)$, depends on initial per capita income Y_0^i, resource abundance Nat^i and a vector of other explanatory variables Z^i:

$$G^i = \alpha_0 + \alpha_1 \ln(Y_0^i) + \alpha_2 Nat^i + \alpha_3 Z^i + \varepsilon^i, \tag{48}$$

where i corresponds to each single U.S. state. Our dependent variable is the average yearly change in real Gross State Product (GSP) per capita between 1994-2000. The results are reported in column entries (3)-(5) of Table 2.

As a first step, we estimate a simple conditional convergence regression (3) with initial income per capita ($Ln Y_{94}$) and our measurement of resource abundance (Nat) as independent variables. Resource abundance proves to be a significantly detrimental factor for economic growth. An increase in income from natural resources of one standard deviation (0.06) decreases the growth rate by about 0.61% per year.

Secondly, additionally to initial income and resource abundance, we incorporate in the analysis a set of other explanatory variables Z^i that potentially affect the rate of income growth. These growth-related characteristics include the share of industrial machinery production in GDP in 1994, the contribution of educational services in GSP in 1994, the ratio of net international migration for 1994-99 for each state relative to the population of the state in 1994, the share of R&D expenditure in GSP for 1995 and the number of prosecuted corrupted public officials over

1994-2000 per 100000 citizens as regional substitutes or proxies for *Investment*, *Schooling*, *Openness*, *R&D* and *Corruption*, respectively. Data on income and schooling are provided by the Bureau of Economic Analysis of the U.S. Ministry of Commerce. Data on openness and corruption are provided by the U.S. Census Bureau and the U.S. Department of Justice respectively.

As depicted in column entry (4) of Table (2), higher levels of investment, schooling, openness, innovation and lower levels of corruption are associated with higher rates of GSP growth. Noticeably, resource abundance now has a positive (although insignificant) impact on economic growth. The explanation for the change in sign of the coefficient is that natural resources frustrate growth by crowding-out the growth-promoting activities captured by Z^i. The vector Z^i seems sufficiently rich to capture most of the indirect negative effects of resource abundance on growth.Column entry (5) reproduces the same results, but by including the role of regional spillovers of R&D, the effect of innovation on growth becomes substantially larger and highly significant.

TABLE 2. *Growth regressions as in equation* (48) *for 1994-2000*

Dependent variable: $G_{1994\text{-}2000}$	(3)	(4)	(5)
Constant	10.02	35.76	34.90
Ln Y$_{94}$	−0.60	−3.32***	−3.27***
(0.15)	(−0.53)	(−2.78)	(−2.78)
Nat	−10.23***	1.21	1.38
(0.06)	(−3.55)	(0.37)	(0.44)
Investment		0.30*	0.27*
(1.01)		(1.78)	(1.71)
Schooling		1.23***	0.92**
(0.38)		(2.67)	(1.97)
Openness		6.29***	5.68***
(0.09)		(2.74)	(2.58)
Corruption		− 0.34***	− 0.28**
(1.34)		(−2.80)	(−2.36)
R&D		0.19	
(1.12)		(1.17)	
Innov			0.54**
(0.79)			(2.28)
R^2 adjusted	0.19	0.45	0.50
N	49	49	49

Note: Standard deviations for independent variables in parentheses, based on the sample *N*=49 of regression (7); t-statistics for coefficients in parentheses. Superscripts ∗, ∗∗, ∗∗∗ correspond to a 10, 5 and 1% level of significance.

By substitution of equation (47) into (48), where Z^i, β_0, β_1, β_2 and μ^i are specified for investment, schooling, openness, R&D and corruption, we can identify the transmission mechanisms, that is the direct and indirect impact of natural resources on growth:

$$G^i = (\alpha_0+\alpha_3\beta_0) + (\alpha_1+\alpha_3\beta_1)\ln(Y_0^i) + (\alpha_2+\alpha_3\beta_2)Nat^i + \alpha_3\mu^i + \varepsilon^i, \tag{49}$$

where $\alpha_2 R^i$ denotes the direct effect of natural resources on growth, $\alpha_3\beta_1 R^i$ indicates the indirect effect of natural resource abundance on growth, and μ^i are the residuals of equation (47). The estimated values for the coefficients α_1, $\alpha_2+\alpha_3\beta_1$, and α_3 of equation (49) are listed in column (6) of Table 3.

TABLE 3. *Growth regression, taking account of indirect effects as in equation (49)*

Dependent variable: $G_{1996\text{-}2000}$	(6)	(7)
Constant	10.02	10.02
Ln Y_{75} (0.15)	−0.60 (−0.65)	−0.60 (−0.68)
Nat (0.06)	−10.23*** (−4.31)	−10.23*** (−4.50)
Investment (μ_1) (0.97)	0.30* (1.78)	0.30* (1.78)
Schooling (μ_2) (0.33)	1.23** (2.67)	1.23** (2.67)
Openness (μ_3) (0.07)	6.29*** (2.74)	6.29*** (2.74)
Corruption (μ_4) (1.27)	−0.34*** (−2.80)	−0.34*** (−2.80)
R&D (μ_5) (0.98)	0.19 (1.17)	
Innov (μ_5) (0.68)		0.54** (2.28)
R^2 adjusted	0.45	0.50
N	49	49

Note: Standard deviations for independent variables in parentheses; t-statistics for coefficients in parentheses. The parentheses next to the variable names represent the sequence of residuals used in each regression. Superscripts *, **, *** correspond to a 10, 5 and 1% level of significance.

We quantify the relative importance of innovation in explaining the overall negative impact of natural resources on growth. The direct effect is given by α_2 and the indirect effect by $\alpha_3\beta_2$, as can be seen from equation (49). Results for these variables are listed in Tables 4 and 5, for regressions (4)/(6) and (5)/(7), respectively. The two tables indicate that a one standard deviation, or 6 per cent point, increase in resource income decreases growth by 0.6%. When cumulated over years, such a growth differential can cause large income gaps. The relative contribution of the innovation channel on the overall impact of resource wealth on long-term income amounts to 14 or 34%, depending on whether regional R&D spillover effects are taking into account.

TABLE 4. *Indirect Effects through R&D*

Transmission channels	α_2 (Table 2)	α_3 (Table 2)	β_2 (Table 1)	$(\alpha_2; \alpha_3\beta_2)$ (Table 3)	Relative Contribution
Natural Resources	1.21			1.21	−12%
R&D		0.19	−8.00	−1.52	14%
Other				−8.50	98%
Total				**−10.23**	**100%**

TABLE 5. *Indirect Effects through R&D with spillovers (Innov)*

Transmission channels	α_2, (Table 2)	α_3 (Table 2)	β_2 (Table 1)	$(\alpha_2; \alpha_3\beta_2)$ (Table 3)	Relative Contribution
Natural Resources	1.38			1.38	−13%
R&D		0.54	−6.20	−3.34	34%
Other				−5.68	79%
Total				**−10.23**	**100%**

5. CONCLUSIONS

During the past decades, economists tried to explain why resource abundant countries embark on a development path that leads to stagnation and economic decline rather than affluence and prosperity. Resource wealth did not prove to be the panacea to underdevelopment. On the contrary, resource dependence exacerbated poverty and retarded economic growth over the past three decades. With a few exceptions, such as those of Botswana, Norway and Iceland, resource-abundant countries tend to belong to the list of development failures.

Several indirect mechanisms through which natural resources frustrate income growth have been identified in the literature. Resource wealth can deteriorate the terms of trade, reduce human capital accumulation, increase corruption and rent-seeking, increase public spending and result in political instability. In this paper, we investigate a transmission channel not extensively discussed in the literature: the relationship between resource abundance and innovation. Innovation is undoubtedly one of the main determinants of economic growth, by enhancing the productivity of labor and capital. The pursue of innovators for 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 identify the correlation between resource abundance and innovation for a more extensive sample of countries and potentially disentangle the effect of natural resources into 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.

APPENDIX 1: DERIVATION OF STEADY-STATE DYNAMICS

Incorporating equation (41) into equations (38), (39) and (40) yields:

$$l_{ss}^{\frac{\alpha-1}{\alpha}} \hat{k}_{ss}^{\frac{\alpha-1}{\alpha}} \left(\frac{\alpha}{N}\right)^{\frac{1}{\alpha}} (1+\alpha N) - \rho - l_{ss} N = 0, \tag{50}$$

$$l_{ss}^{\frac{\alpha-1}{\alpha}} \hat{k}_{ss}^{\frac{\alpha-1}{\alpha}} \left(\frac{\alpha}{N}\right)^{\frac{1-\alpha}{\alpha}} (1+\alpha) + G - \frac{\hat{c}_{ss}}{\hat{k}_{ss}} - l_{ss} N = 0, \text{ and} \tag{51}$$

$$\hat{c}_{ss} = \frac{N(1-\alpha)}{\alpha(1+\sigma)} l_{ss}^{-\sigma} \hat{k}_{ss}. \tag{52}$$

Incorporating equation (52) into (51) yields:

$$l_{ss}^{\frac{\alpha-1}{\alpha}} \hat{k}_{ss}^{\frac{\alpha-1}{\alpha}} \left(\frac{\alpha}{N}\right)^{\frac{1-\alpha}{\alpha}} (1+\alpha) + G - \frac{1-\alpha}{1+\sigma} \left(\frac{\alpha}{N}\right)^{-1} l_{ss}^{-\sigma} - l_{ss} N = 0. \tag{53}$$

Rearranging equation (50) yields:

$$\hat{k}_{ss}^{\frac{\alpha-1}{\alpha}} = (\rho + l_{ss}N)\left(\frac{\alpha}{N}\right)^{-\frac{1}{\alpha}}(1+\alpha N)^{-1}l_{ss}^{\frac{1-\alpha}{\alpha}}. \tag{54}$$

Incorporating equation (54) into (53) solves for the steady-state value of labor intensity in equation (42).

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