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Resumen

Una condición importante para que se produzca convergencia entre países es que estos compartan la misma función de producción agregada (Solow, 1956). Sin embargo, si los países producen un distinto *mix* de productos, entonces la función de producción agregada diferirá. Este trabajo argumenta que la inclusión de un factor fijo, como los recursos naturales, determinan significativamente el patrón de producción y de comercio de un país y, de esta forma, la senda de acumulación del capital (Leamer, 1987) y el nivel de consumo per capita de una economía pequeña. Para esto, el trabajo construye un modelo dinámico de ventajas comparativas. Este genera que países con distintas dotaciones de factores puedan llegar a distintos estados estacionarios. Los principales resultados del trabajo son los siguientes. Primero, las diferencias en ingreso y capital per capita entre países que carecen y poseen recursos naturales (o que tienen diferentes tipos de estos) se explica por la renta del factor recurso natural y por la razón capital-trabajo, ambos relativos al de los otros sectores. Una economía que descubre recursos naturales disfrutará, en casi todos los casos, de un mayor nivel de consumo per capita en estado estacionario en relación con una economía que no posee este tipo de recursos. En el trabajo se discute un caso específico en el cual no es óptimo explotar los recursos naturales. Segundo, en economías que no poseen recursos naturales, la industrialización siempre es buena en términos de mayor consumo. No obstante, países con recursos naturales pueden terminar con sectores productivos menos industrializados y, aun así, gozar de un mayor nivel de consumo.

Abstract

An important condition for convergence is that countries share the same technology for the aggregate production function (Solow, 1956). If countries produce a different mix of products, however, they will have a different aggregate production function. We argue that the inclusion of a fixed factor, such as natural resources, strongly determines the pattern of production and trade, and thus the path of development (Leamer, 1987) and the level of per capita consumption of a small open economy. We build a dynamic model of comparative advantages that naturally leads to different steady-state equilibria. Our main findings are, first, that differences in income and capital per worker between countries with and without natural resources (and with different types of natural resources) are explained by the relative rent of the natural resource factor and the capital-labor ratio used in the natural resource sector relative to the other sectors. An economy that discovers a natural resource will almost always enjoy a higher level of consumption in steady state, although we describe one specific case in which it is not optimal to exploit the natural resource. Second, for economies without natural resources, becoming industrialized is always good (in terms of consumption). Nevertheless, countries with natural resources could end up with a less industrialized productive sector, but a higher level of consumption.

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1 Introduction

The observed economic performance of countries over the last century has been very dissimilar. Differences in growth rates and per capita income are still open issues, and economists have made a great effort to find the "right conditionals" behind the convergence prediction of the neoclassical growth model. Arguments regarding the nature of economic policies and the quality of institutions are at the heart of empirical growth papers. The theoretical model underlying these studies is usually a variant of the standard one-sector neoclassical growth model. While this simple framework is useful for explaining many of the empirical findings, we find that the one-sector model hides relevant development paths that can be explored using models with more than one sector. In particular, an important condition for convergence is that countries share the same technology for the aggregate production function. If countries produce a different mix of products, however, they will exhibit different aggregate production functions.

This paper argues that introducing a sector that uses a fixed factor as an input, as in the case of natural resources, provides a better understanding of the cross-country differences in the per capita income level and the production structure. Using natural resources as a variable for explaining growth is not new, but the current view is to treat them as a proxy for the size of rent-seeking activities, which are detrimental to growth. We assert that when natural resources are included as another production factor, they strongly determine the pattern of production and trade—and thus the development path of a small open economy. Natural resources are usually a blessing, but under certain conditions, they could become a curse. Using a dynamic model of comparative advantages, we show that the driving forces of these results are simply trade, specialization, factor abundance, and factor intensity. This provides an alternative explanation to the view that abundant natural resources are a source of corruption.

We are interested in three aspects of development: the path of development; the level of per capita income/consumption (welfare); and industrialization or output composition. The kind of issues that we have in mind are, for example, why Finland and Argentina now have different per capita income levels and production structures despite having started with almost the same capital per worker at the beginning of the last century; or why Japan and Sweden have similar levels of income per capita, while the former has twice as much capital per worker as the latter. Moreover, Álvarez and Fuentes (2006) find that for countries abundant in mineral resources it is more difficult to have positive net exports of the industrial good compared to economies endowed with agricultural land or forestry resources. The conventional answer to many of these questions lies in the quality of policies and institutions, two variables that have been

important in explaining why natural resources countries grow less than non-abundant countries. Without denying the importance of those findings, we offer a new explanation based on the more traditional view of trade and growth.

This paper can be viewed as an extension of the neoclassical growth model (Solow, 1956) for a closed economy (here, open to trade). In contrast with the seminal work of Solow, however, we allow the aggregate production function to differ from country to country, since the economies can produce different mixes of output. When we add more factors and goods, the traditional approach to analyzing convergence, which assumes equal production functions for all economies, is no longer valid. In that respect, our paper is related to the work of Leamer (1987). With three factors and n goods, the traditional model of international trade is able to generate several cones of diversification characterized by factor price equalization within each cone. The model thus generates a rich set of development paths, characterized by different patterns of production as the economy accumulates physical capital and transits from one diversification cone to the next.

In Leamer (1987), capital accumulation is exogenous and the dynamics are not modeled. Atkenson and Kehoe (2000) use a dynamic Heckscher-Ohlin model (with two goods and two factors) to examine why countries under free trade do not converge to the same level of per capita output. In this setting, an economy that develops later (and starts with a low labor-capital ratio) ends up with a permanently lower level of income relative to the economies that started their development process earlier. Thus, while Leamer (1987) provides a picture with a rich set of development paths when countries accumulate capital in a setting with three factors and n goods, Atkenson and Kehoe (2000) concentrate on the dynamics and the implications for the convergence process, but in a two-by-two framework in which the development paths are less interesting. The recent literature features many papers that study the long-run equilibrium in a dynamic Heckscher-Ohlin model, including Chen (1992), Baxter (1992), Ventura (1987), Cuñat and Maffezzoli (2003), and Bajona and Kehoe (2006). These papers mainly study how trade can generate a variety of long-run equilibria, and they build frameworks to replicate some aspects of the empirical growth literature. We claim that introducing a natural resource sector allows us to explain many of the stylized facts.[1] As in many of the previous works quoted, we are also able to generate different long-term equilibria.

Our framework is a dynamic model of comparative advantages for a small open economy with three tradable goods and one nontradable good. As a small economy, it takes the prices of

[1] See, for example, Álvarez and Fuentes (2006), who present stylized facts on how natural resources affect the production structure and trade patterns in both the transition period and the steady state.

the tradable goods in the world market as given. One of the tradables sectors uses natural resources, capital, and labor as production factors, while the other two (namely, labor-intensive manufacturing and capital goods sectors) use only capital and labor. The nontradables sector uses only labor. The production functions are a Leontief type with different input intensities.[2] We derive the steady state and the development path of the economy with and without natural resources. We show that the type of natural resources—more precisely, the intensity of capital per worker used in this sector relative to the other sectors—is the key variable that leads the pattern of specialization and determines the steady-state level of per capita consumption. We also offer an explanation of why some countries could become more industrialized than others and why some countries have less incentive to accumulate capital than others.

Our main findings are threefold. First, once we allow for the possibility of producing in more than one sector, the model naturally leads to the existence of several steady-state equilibria. This outcome follows from the fact that economies will converge to different cones of diversification that leave them, in the long run, with a different level of capital per worker. This result is obtained in a similar fashion as in Atkenson and Kehoe (2000) under the standard case without natural resources. Here, however, we emphasize the implication of having or not having natural resources and, particularly, how the type of natural resources conditions the steady-state equilibrium. For this purpose, we build on the simplest model (without any endogenous growth engine), in which all economies share the same technology (so each ends up with the same return on its productive factors) and only differ in the type and size of the natural resource. The steady-state level of per capita income will thus depend only on the incentives for capital accumulation driven by the type of natural resource available.

Second, the differences in income per capita and capital per worker observed between countries with and without natural resources (and within the group that has different types of natural resources) are explained by two key variables: the capital-labor ratio used in the natural resource sector relative to the other sectors in the economy; and the rent provided by the natural resource factor. We show that if an economy discovers natural resources and this sector is more capital-intensive than the capital goods sector, the economy will unambiguously enjoy a higher level of both per capita income and consumption. This stems from the incentives for further capital accumulation. In this case, natural resources are a blessing. Nevertheless, if this sector is more labor-intensive than the labor-intensive manufacturing sector, the final effect is ambiguous: the economy is richer thanks to this endowment, but its level of consumption may be lower in steady

[2] The model with two factors, two tradable goods, and one nontradable good closely follows Claro (2005), although Claro uses the model to explain capital flows in a financially integrated world.

state if it loses capital on its path to the new steady state. The final result will depend on whether the additional income provided by the natural resource compensates the rent lost though the decreasing capital. In this setting, under certain restrictive conditions, natural resources are a curse. This result follows the assumption that all factors are fully employed. That means that from an optimal point of view, it may be efficient not to exploit the natural resource.

Finally, we find that economies with a higher level of natural resources could end up having a less industrialized productive sector, but enjoying a higher level of consumption. In the limit, if the rent provided by the natural resource is too high, the economy may not produce any other good except for the nontradable and the one associated with the natural resource sector. On the other hand, depending on the type of natural resource and the rent it provides, the economy could also wind up producing capital-intensive goods and no labor-intensive manufactured goods. For those economies without natural resources, industrializing is always good as it allows them to enjoy a higher level of consumption (Atkenson and Kehoe, 2000). This is no longer the case, however, when we allow for natural resources to play a role.

The rest of the paper is organized as follows. Section 2 presents the analytical model, and section 3 analyzes the equilibria with and without natural resources. Section 4 presents the relationship between natural resources and paths of development, highlighting the relevance of the sector's capital intensity and rents. We also briefly discuss some welfare aspects and industrialization patterns. Section 5 concludes.

2 The Model

Building on the frameworks developed by Atkenson and Kehoe (2000) and Claro (2005), we model a small open economy that faces tradable goods prices as given. There are three tradables sectors and one nontradables. In the spirit of Heckscher-Ohlin, we assume the same preferences, the same technology to produce each good in all countries, and no cross-country factor mobility. Comparative advantage will thus be driven by relative factor endowments. The three tradables sectors are classified as labor intensive, capital intensive, and natural resource intensive. The latter may or may not be available for the economy. Households consume the labor-intensive manufactured good, the natural resource commodity, and the nontradable good. The capital good is not consumed, but is used to accumulate capital.

2.1 Consumers

The representative household maximizes an intertemporal utility function of a consumption basket, C, composed of the manufactured good (M), the natural resource commodity (F), and the nontradable good (N); ρ stands for the subjective discount rate. Preferences correspond to a constant elasticity of substitution (CES) utility function with intertemporal substitution equal to one. Lowercases refer to variables in per worker terms.

$$U = \int_0^\infty \ln c \; e^{-\rho t} dt \tag{1}$$

Aggregate consumption is collected through a Cobb-Douglas function defined as

$$c = m^{1/3} f^{1/3} n^{1/3} \tag{2}$$

Supplies are defined as m^s, f^s, and n^s. The intratemporal problem is given by the following Lagrangian function, expressed in terms of the manufactured good (the numeraire):

$$\mathcal{L} = m^{1/3} f^{1/3} n^{1/3} - \theta \left[m + p_f f + p_n n + p_x x - y \right] \tag{3}$$

where y corresponds to the income earned and p_i to the price of good $i = f, x, n$ relative to good m. The first-order conditions are given by:

$$\begin{array}{ll} [m] & \frac{1}{3} m^{-2/3} f^{1/3} n^{1/3} = \theta \\ [f] & \frac{1}{3} f^{-2/3} m^{1/3} n^{1/3} = \theta p_f \\ [n] & \frac{1}{3} n^{-2/3} f^{1/3} m^{1/3} = \theta p_n \end{array} \tag{4}$$

With these conditions, we solve for the aggregate index:

$$c = m^{1/3} \left(\frac{m}{p_f} \right)^{1/3} \left(\frac{m}{p_n} \right)^{1/3} = m \left(p_n p_f \right)^{-1/3} \tag{5}$$

The economy demands the capital good, x, to accumulate capital, k, that depreciates at the rate δ. The capital-labor ratio of this economy evolves as

$$\dot{k} = x - \delta k \tag{6}$$

The economy has no access to capital flows, so its current account is always balanced, defining the following budget constraint (in units of labor) at any moment of time:

$$m + p_x x + p_f f + p_n n = w + rk + \phi t \tag{7}$$

where w, r, and ϕ correspond to the return on labor (L), capital (K), and the natural resource (T). The representative agent solves the dynamic problem of maximizing equation (1) subject to equations (6) and (7). The Hamiltonian for the problem is written as

$$H = \ln c \; e^{-\rho t} + \lambda \left(\frac{w + rk + \phi t - 3c \left[p_n p_f \right]^{1/3}}{p_x} - \delta k \right) \tag{8}$$

Time subscripts are omitted to simplify the notation. The optimal paths for capital and consumption are given by

$$\frac{\dot{c}}{c} = \left(\frac{r}{p_x} - \delta - \rho \right) - \frac{1}{3} \left(\frac{\dot{p_n}}{p_n} + \frac{\dot{p_f}}{p_f} \right) + \frac{\dot{p_x}}{p_x} \tag{9}$$

$$\dot{k} = \frac{w + (r - \delta p_x)\, k + \phi t - 3c(p_n p_f)^{1/3}}{p_x} \tag{10}$$

As usual, $\dot{z}$ corresponds to the time derivative of variable z.

2.2 The Firms

Production of $j = M^s$, N^s, F^s, X^s is characterized by Leontief technology. We denote with a_{ij} the requirement of factor i= K, L, T to the production of one unit of good j. Constant returns to scale and perfect competition ensure that the following zero-profit conditions hold for each sector:

$$1 = a_{Lm} w + a_{Km} r \tag{11}$$

$$p_x = a_{Lx}w + a_{Kx}r \tag{12}$$

$$p_f = a_{Lf}w + a_{Kf}r + a_{Tf}\phi \tag{13}$$

$$p_n = a_{Ln}w \tag{14}$$

Leontief technology plus the nontradables sector ensure full employment of every factor in equilibrium. The factor-market-clearing conditions are

$$1 = a_{Lm}m^s + a_{Lf}f^s + a_{Lx}x^s + a_{Ln}n^s \tag{15}$$

$$k = a_{Km}m^s + a_{Kf}f^s + a_{Kx}x^s \tag{16}$$

$$t = a_{Tf}f^s \tag{17}$$

In addition, the market for nontradables must clear at all times:

$$n = n^s \tag{18}$$

3 Competitive equilibrium

In this section, we solve the dynamic model to find the steady-state equilibrium and the stable path for capital and aggregate consumption. As a benchmark, we first present the case for an economy without natural resources. We then analyze how the equilibrium shifts when the country discovers natural resources, focusing on its link to the capital-labor intensity of the natural resource sector.

3.1 Equilibrium without natural resources

Consider the case of a small open economy without natural resources. Its development path is characterized by the dynamics of consumption and capital given by equations (9) and (10). In addition to this economy, the model includes a large economy that sets international prices and that is already in steady state.[3] Here we use the steady-state assumption to simplify the

[3] Atkenson and Kehoe (2000) call these economies the early bloomer (for the large economy) and the late bloomer (for the small economy).

first-order conditions by assuming that the international prices of goods are constant. This assumption is not restrictive, since a change in relative prices in the world market will cause a shift in the diversification cones derived in the model, as well as in the long-run equilibrium for the small economy. For instance, if we allow for technological changes at different rates in different sectors, relative prices will adjust and the diversification cone will shift accordingly. The small open economy will reach the region of $\dot{c} = 0$ only when $r = r^*$, that is, when the domestic interest rate equals the international rate.[4] In this region, firms are indifferent in their choice of producing any mix of goods. We call this situation the full diversification case.

To characterize this steady state, we study the conditions for producing the two tradable goods (m and x) and the nontradable good. Since the economy does not have natural resources, the presence of two factors and two tradable goods implies that the factor rewards are given by the international prices of tradable goods, as stated in equations (11) and (12). The price of the nontradable good is determined only by supply-side conditions (see equation 14). To produce both tradable goods, the capital-labor ratio net of labor used by the nontradables sector must lie between the capital-labor ratio used in the manufacturing sector and the capital goods sector. That is,

$$k_x \geq \frac{k}{1 - a_{Ln} n} \geq k_m \tag{19}$$

From here we can obtain the possible values of n:

$$\frac{k_x - k}{k_x a_{Ln}} \geq n \geq \frac{k_m - k}{k_m a_{Ln}} \tag{20}$$

From equations (4) and (5) we obtain a relationship between n and c, the consumption basket. Combining these equations with equation (20) yields the possible values for consumption under full diversification as a function of the capital-labor ratio of the economy.

$$\frac{{p_n}^{2/3}}{{p_f}^{1/3} a_{Ln}} \left(\frac{k_x - k}{k_x} \right) \geq c \geq \frac{{p_n}^{2/3}}{{p_f}^{1/3} a_{Ln}} \left(\frac{k_m - k}{k_m} \right) \tag{21}$$

Since the economy is producing in the diversification cone, $p_n = a_{Ln} w^*$, where w^* represents the international wage rate. Thus the bounds for consumption are

[4] An asterisk on a variable denotes international values.

$$\frac{w^{*2/3}}{(p_f a_{Ln})^{1/3}}\left(\frac{k_x-k}{k_x}\right) \geq c \geq \frac{w^{*2/3}}{(p_f a_{Ln})^{1/3}}\left(\frac{k_m-k}{k_m}\right) \tag{22}$$

Equation (22) provides the combination of c and k that allows for full diversification. Another condition that must be imposed is that of nonnegative investment. This condition is given by

$$x = \frac{w^* + r^* k - 3c\left(a_{Ln} w^* p_f\right)^{1/3}}{p_x} \geq 0 \tag{23}$$

That is,

$$c \leq \frac{w^* + r^* k}{3\left(a_{Ln} w^* p_f\right)^{1/3}} \tag{24}$$

The diversification cone given by equation (22) is truncated according to equation (24), as shown in figure 1. Having described the conditions for $\dot{c} = 0$, we now analyze the conditions for capital accumulation. If the rest of the world has reached its steady state, then $r^* = p_x(\delta + \rho)$ and $\dot{k} = 0$ implies the following positive relation between k and c.

$$\dot{k} = 0 \Rightarrow c = \frac{1}{3}\left(\frac{w^* + \left(r^* - \delta p_x\right) k}{\left[a_{Ln} w^* p_f\right]^{1/3}}\right) \tag{25}$$

Note that c is an increasing function of k and the condition of nonnegative investment is never binding in steady state, since $x \geq 0$ lies above $\dot{k} = 0$ (see figure 1). By combining equations (25) and (22), we obtain the range for k consistent with a steady-state equilibrium and full diversification:

$$\overline{k} \equiv \frac{2k_x w^*}{3w^* + \left(r - \delta p_x\right) k_x} \geq k \geq \frac{2k_m w^*}{3w^* + \left(r - \delta p_x\right) k_m} \equiv \underline{k} \tag{26}$$

For $k < \underline{k}$, $\dot{k} = 0$ is still an upward-sloping function. Outside the diversification cone, however, the price of the nontradable good is not given by external conditions, since both the wage rate and the price of n increase as the economy accumulates capital. Thus, the $\dot{k} = 0$ curve is concave. While in this region, the economy always produces the nontradable good, and the fact that the economy only produces one tradable good (the labor-intensive manufactured good) makes all prices dependent on domestic conditions. From equation (9) we obtain that in this

region $\dot{c} > 0$, so the unique possible path toward a steady state is given by the saddle path in which $\dot{k} > 0$. The economy accumulates capital until converging to the edge where $k < \underline{k}$. At this point the economy has no incentive to accumulate further, since $r = r^*$ and prices are again determined only by external conditions and $\dot{k}$ and $\dot{c}$ are simultaneously equal to zero. For all ranges of k, $\dot{k} = 0$ is continuous in k.

This steady-state equilibrium is characterized by relatively low capital and income per worker and the production of the labor-intensive manufactured good and the nontradable good. This is the prediction from Atkenson and Kehoe (2000). A poor country will inevitably end up with a lower income per worker. We show that this prediction no longer needs to hold when natural resources are included. The steady-state capital-labor ratio is said to be relatively low since the equilibrium with natural resources can lead the economy to a lower k in steady state. An analogous result follows when $k > \overline{k}$. In that case, the economy will produce the nontradable and the capital good.

3.2 Equilibrium with natural resources

Next we analyze the case of an economy endowed with natural resources. Figure 2 shows the capital-labor ratio for goods m and x, labeled k_m and k_x. For example, if we assume that the capital-labor ratio net of labor used in the nontradables sector of the aggregate economy is located at point E and that the economy has an endowment of natural resources, then the natural resource sector will absorb capital and labor available to the other two sectors. If the natural resource sector is more capital-intensive than x, then the endowment available for the other two tradables sectors could move from E to a point like C (provided that the new equilibrium for the nontradables leaves the economy at such a point). The economy will be out of the full diversification cone, so returning to equilibrium will require accumulating capital up to the point where it reaches the edge of the diversification cone (point E^{C})—that is, where the capital-labor ratio net of factors used in the nontradables and natural resource sectors equals k_m. At that point, the economy will not produce the capital good, and the accumulation of capital will stop.

On the other hand, if the natural resource sector is more labor intensive than m, the endowment available for the other two tradables sectors could move from E to a point like A. The economy will again be out of the full diversification cone, but now it will converge to the edge where it produces x and does not produce m (point E^{A}). The capital-labor ratio net of capital and labor used in the natural resource and the nontradables sectors will equal k_x in steady state.

As in the previous section, we formally derive the conditions for an economy that produces all four goods (that is, the full diversification case). In this situation, the return on the three factors is determined only by the world prices of the three tradable goods (equations 11 to 13). Moreover, supply-side conditions determine the real exchange rate (in terms of the manufactured good) according to equation (14). Later, we study the steady-state equilibrium, which is consistent with full diversification. As mentioned above, the final equilibrium depends on the capital intensity of the natural resource sector relative to that of the other tradables sectors.

For a country to be producing in region B (see figure 2), the capital-labor ratio, net of the capital and labor used in the natural resources sector and net of labor used by the nontradables sectors (defined as k_n), has to be between the capital-labor ratio used by manufacturing and that used in the capital goods sector. In figure 2, straight lines from the origin represent the capital - labor intensities in each sector. Dashed lines represent the bounds of diversification cones once labor devoted to non-tadables is substracted from the total endowment of labor.

$$k_x \geq \widetilde{k_n} \geq k_m \tag{27}$$

Equation (28) defines possible values for n consistent with complete diversification, where $tf = a_{Tf}/a_{Lf}$ (the land per worker used in the natural resource sector):

$$\frac{k_x - k + \frac{t}{t_f}(k_f - k_x)}{k_x a_{Ln}} \geq n \geq \frac{k_m - k + \frac{t}{t_f}(k_f - k_m)}{k_m a_{Ln}} \tag{28}$$

From the former conditions, and given that n cannot be negative and the price of nontradables is solely determined by external conditions, combining (28) with (4) and (5) yields the following conditions for the level of consumption per worker consistent with the production of all four goods:

$$\bar{c} \equiv \frac{w^{*2/3}\left\{1 - (k/k_x) + (t/t_f)\left[(k_f/k_x) - 1\right]\right\}}{(p_f a_{Ln})^{1/3}} \geq c \geq \frac{w^{*2/3}\left\{1 - (k/k_m) + (t/t_f)\left[(k_f/k_m) - 1\right]\right\}}{(p_f a_{Ln})^{1/3}} \equiv \underline{c} \tag{29}$$

We add two necessary conditions for equation (29) to be satisfied:

$$
\begin{aligned}
k_1 &\geq k_f \tfrac{t}{t_f} \\
k_2 &\leq k_x + \tfrac{t}{t_f}\left(k_f - k_x\right)
\end{aligned}
\tag{30}
$$

The diversification cone no longer starts at $k = 0$ as in the case without natural resources, since the full employment of natural resources requires at least a k given by the first condition in equation (30). The second condition is needed for the nontradables to remain positive. As in the previous case, the limits for k depend on the demand for nontradables or—equivalently—on the level of consumption per worker. Figure 3 displays the combinations of c and k at which the economy is fully diversified. The presence of natural resources affects the range for consumption and capital per worker within which the economy produces all goods. These bounds depend on the capital intensity of the natural resource sector relative to the other sectors. When an economy produces all four goods, its factor prices are given by external conditions, which means that $\dot{w} = \dot{r} = \dot{\phi} = 0$, so $\dot{c} = 0$:

$$
\frac{\dot{c}}{c} = \left(\frac{r}{p_x} - \frac{r^*}{p_x}\right) = 0 \tag{31}
$$

The condition for the production of the capital good to be positive provides another bound for k and c. This can be written as follows:

$$
x = \frac{w^* + r^* k + \phi^* t - 3c\left(a_{Ln} w^* p_f\right)^{1/3}}{p_x} \geq 0 \Rightarrow c \leq \frac{w^* + r^* k + \phi^* t}{3\left(a_{Ln} w^* p_f\right)^{1/3}} \tag{32}
$$

The expression for the law of motion of capital is

$$
\dot{k} = \frac{w^* + \left(r^* - \delta p_x\right) k + \phi^* t - 3c(p_n p_f)^{1/3}}{p_x} \tag{33}
$$

Since $r^* = p_x(\delta + \rho)$ and that $\dot{k} = 0$, we obtain the following positive relation between k and c:

$$
c = \frac{1}{3}\left(\frac{w^* + p_x \rho k + \phi^* t}{\left[a_{Ln} w^* p_f\right]^{1/3}}\right) \tag{34}
$$

As shown in figure 3, $\dot{k} = 0$ is linear within the region for $\dot{c} = 0$. All possible state equilibria lie over the straight line, $\dot{k} = 0$, between $\underline{k}$ and $\overline{k}$. These values are obtained by equating equation (34) with the limits given by equation (29):

$$\overline{k} \equiv \frac{k_x \left\langle w^* \left\{2 + (3t/t_f)\left[(k_f - k_x)/k_x\right]\right\} - \phi^* t \right\rangle}{3w^* + (r^* - \delta p_x) k_x} \geq k \geq \frac{k_m \left\langle w^* \left\{2 + (3t/t_f)\left[(k_f - k_m)/k_m\right]\right\} - \phi^* t \right\rangle}{3w^* + (r^* - \delta p_x) k_m} \equiv \underline{k} \tag{35}$$

Figure 3 also presents the optimal saddle path for this economy. If the production of the natural resource good leaves the rest of the economy with a relatively low (high) capital-labor ratio, it will converge to a steady state in which it produces all goods except the capital good (labor-intensive manufactured good). Thus, the group of countries with natural resource endowments may present different steady-state values for the capital-labor ratio, output composition, and per worker income, independently of having started with the same capital-labor ratio.

4 Natural Resources and the Development Path

In this section we compare the equilibriums with and without natural resources. We compare the steady state equilibrium for both cases and we analyze the development path followed for a country that discovers a natural resources.

4.1 Steady-state equilibrium

Our focus here is on comparing the new equilibrium with that of countries without natural resources. Natural resources will affect the function for $\dot{k} = 0$. The latter can be seen by comparing equations (25) and (34), where the difference is ϕt. For an economy with natural resources, the function $\dot{k} = 0$ will thus lie somewhere above the function for an economy without them. This shows that at each level of k, the economy is able to enjoy a higher level of consumption (see figure 4). The range for $\dot{c} = 0$ may also be affected by the presence of natural resources, depending on the capital intensity of the different sectors. The set of all possible equilibria will be given by equation (26) for the case without natural resources and by equation (35) for the case with natural resources. Comparing the limits from those inequalities, we state that the minimum (maximum) capital per worker in steady state will be higher if equation (36) is positive (negative):

$$\left(\frac{k_f}{k_i} - 1\right) - \frac{t_f \, \phi^*}{3w} \gtrless 0, \qquad i = m, x \tag{36}$$

Figures 4 to 6 compare examples of the possible steady-state equilibria for an economy with natural resources and one without. The equilibria depend on the capital-labor ratio used in the natural resource sector relative to the capital-labor ratio used in m or x, and on the ratio of the natural resources to labor payment ($t_f \phi^*/w$). The larger the rent obtained by the owners of the natural resources vis-à-vis the amount received by the workers, the smaller the capital ratio in steady state, all things equal. If compensation from natural resources is very high, the economy will not need to accumulate capital to enjoy a higher level of consumption: in that sense, the availability of natural resources is a blessing. However, the best variable for assessing welfare is consumption. When we compare the minimum and maximum possible values for consumption in steady state for the case with and without natural resources (Δc_{ss}), while restricting the economy to fully employing its resources, the steady-state level of consumption will rise if the sign of equation (37) is positive. However, since the total effect on welfare includes the changes in consumption during the transitional dynamics, consumption and capital per worker could rise in the transition but then drop to a lower level in the steady state. The final result will thus depend on the present value of utility generated by this stream of consumption. Again the results will depend on the capital-labor ratio used in each industry relative to the natural resource sector and the rent received by the owners of the natural resources.

$$\Delta c_{ss} = \phi^* + \frac{1}{t_f}\left(r^* - \delta p_x\right)\left(k_f - k_i\right) \gtrless 0, \qquad i = m, x \tag{37}$$

As posted, Δc_{ss} may be negative. This result is driven by the assumption of full employment of all factors. However, if not exploiting is a possible choice, then having natural resources can never be welfare reducing. Given the Leontief nature of the production function, the choice is to exploit the total stock of natural resources or none at all, so there is no incentive to exploit just some proportion of the stock.

4.2 The Transition Following a Natural Resource Discovery

Next, we analyze what happens when an economy without natural resources discovers a natural resource. We distinguish three cases.

Case 1: $k_f > k_x > k_m$

Assume that an economy with no natural resource is in steady state. This is shown in figure 4 for points within $\underline{c}$ and $\overline{c}$ on the function $\dot{k} = 0$. Suppose now that this economy discovers

a natural resource. If the natural resource sector is the most capital intensive of the economy, then both functions, $\underline{c}$ and $\overline{c}$, will move rightward according to equation (29). The new bounds are $\underline{c'}$ and $\overline{c'}$. The $\dot{k} = 0$ function jumps to $\dot{k'} = 0$. The new range for capital per worker compatible with diversification can be lower or higher than the range without natural resources, depending on the sign of equation (36). Nevertheless, the level of income and consumption per worker unambiguously increases by equation (37), regardless of whether the economy specializes in the manufactured or the capital good or whether the economy started with a low or high capital-labor ratio.

If, prior to the discovery, the economy had a capital-labor ratio below $\underline{k'}$, then it will move toward equilibrium point E_1, as shown by the saddle path in figure 4. If the economy was situated between $\underline{k'}$ and $\overline{k'}$, then consumption will jump and the economy will reach the new equilibrium, E_1', at impact. On the other hand, if the economy was not at steady state and had $k > \overline{k'}$, then it will jump above $\dot{k'} = 0$. It will reduce the capital-labor ratio in steady state, but it will enjoy a higher consumption level. The intuition for this result is that a high return on the natural resource (ϕ) generates a wealth effect that expands the nontradables sector, which requests labor but not capital. The economy therefore reduces the capital-labor ratio in steady state.

As a result of the discovery, the economy will have an equal, higher, or lower steady-state capital-labor ratio, but it will unambiguously enjoy higher income and consumption per worker. However, the output composition may end up quite different from the case without natural resources. For example, if the economy was originally situated between $\underline{k'}$ and $\overline{k}$ (producing all goods), it will converge to E_1 and stop producing the capital good. This could be the case of an economy that discovers a mineral resource that is highly capital intensive: in the new equilibrium, the economy does not produce the capital good and has to import it. Finally, if the rent from the natural resource sector is too high, $\dot{k} = 0$ will move up to the point where neither m nor x are produced. That is, the economy will move to a point close to the vertex of the triangle.

Case 2: $k_x > k_f > k_m$

This case is illustrated in figure 5, where $\underline{c}$ moves to the right and $\overline{c}$ to the left, thereby shrinking the area for $\dot{c} = 0$: The minimum value for $k = \underline{k}$ can increase or decrease according to equation (36). The maximum level for $k = \overline{k}$ will fall. Consumption will rise if the economy converges from the left to a capital-labor ratio of $k = \underline{k}$, but steady-state consumption could decrease if

the economy ends up producing at $k = \overline{k'}$.[5] This will be the case if the return on the natural resource, ϕ, is too low to compensate the revenues provided by the lower amount of capital in steady state, that is, $\phi^* t_f < (r^* - \delta p_x)(k_f - k_x)$.

Again, if the economy was situated at the left of the new k minimum, it will move toward the equilibrium E_2, which is characterized by producing the labor-intensive manufactured good and none of the capital good. If k was located between the new bounds, consumption will jump to a point like E_2', and the economy will instantaneously reach its new steady state. When $k > \overline{k'}$, consumption per worker will jump above $\dot{k'} = 0$ at impact, and the economy will then converge to an equilibrium characterized by no production of the labor-intensive manufactured good. Initially this economy was producing all goods, but in the end it is producing everything except one good. It will lose capital during the transition, ending with a lower capital-labor ratio. Nevertheless, that does not mean that the economy will reduce its consumption. It may still rise if ϕ^* is high enough. In addition, households will enjoy a higher level of consumption in the early stages of the transition, but this level is decreasing toward the new steady state. The final effect is thus ambiguous. The effect depends on whether the total return of the lost capital is compensated by the total return gained through the exploitation of the natural resource.

Case 3: $k_x > k_m > k_f$

This case is illustrated in figure 6. Both limits for consumption move to the left. The possible paths of development are represented by the dotted arrows. If the economy was located in the range $[\underline{k}', \underline{k}]$, (that is, transitioning to the steady state), consumption will jump up to the point E_3' on the curve $\dot{k'} = 0$, and k will remain constant since the economy will automatically be in steady state. In this case, the economy was not initially producing the capital good, but in the new steady state it produces both the manufactured and the capital good (although the economy had an initial capital-labor ratio equal to $\underline{k}'$).

Finally, if the capital-labor ratio was in the $\left[\overline{k'}, \overline{k}\right]$ range before the discovery, consumption will jump up, and the labor-intensive manufactured sector will become noncompetitive. The transition and the steady state will both be characterized by a productive structure composed of the capital good, the natural resource commodity, and the nontradable good. As in the previous case, the economy could end up with lower consumption per worker in the steady state.

[5] This case is not shown in the figure, but it is easily characterized.

5 Concluding Remarks

Building on the basic neoclassical growth model, we show that the discovery of natural resources can determine the development path, the income per capita, and the pattern of production of a small open economy. Within a model characterized by three tradable goods, one nontradable good, and three factors, we make predictions for several types of economies assuming different capital intensities for the various production sectors. The capital goods sector is more capital-intensive than the labor-intensive manufacturing sector, while the nontradable sector uses only labor as input. We obtain interesting results as we vary the capital intensity in the natural resource commodity sector and the rent obtained from the ownership of natural resources.

An economy without natural resources that starts with a relatively low capital-labor ratio will move to a steady state with lower income per worker and no production of the capital good (Atkenson and Kehoe, 2000). As long as the economy stays small, there is no way of escaping this result. If this economy discovers natural resources and the new sector is more capital-intensive than the rest of the economy, households will enjoy a higher consumption level and will have more capital per worker. If the economy was producing both tradable goods before the discovery, the capital goods sector could become noncompetitive in steady state. Nevertheless, welfare measured as consumption and income per worker will be unambiguously higher. In this case, producing only the labor-intensive manufactured good instead of the capital good is not a curse.

Alternatively, if the natural resource sector is more labor intensive than the labor-intensive manufactured good, this economy may produce none of that good, while producing and exporting the capital good. In this case, consumption per worker could be higher or lower, depending on the relative gains in the natural resources sector and the loss of income generated by the reduction in capital per worker. However, if full employment is no longer a restriction, welfare is not reduced as long as the natural resource is not exploited As in the previous case, there is no direct link between industrialization (understood as producing the capital good) and welfare.

One aspect worth exploring in a further work is the parallel between these findings and the Dutch disease prediction. The discovery of a natural resource may lead the economy to stop producing one of the tradable goods. However, the mechanism is different from the real exchange rate argument emphasized in the Dutch disease literature. In our model, depending on the structure of the natural resource sector, the real exchange rate may depreciate or appreciate on impact (at the moment of the discovery) and move in the opposite direction during the transitional

dynamic.

Another valuable application of this framework would be to analyze the impact of China's entry into the global economy. The diversification cones and the steady state depend crucially on the relative prices of goods (and factors). Knowing how these prices will change provides insight into how production structures will evolve for the different types of economies (with or without natural resources and with different types of natural resources).

In summary, including natural resources in the analysis enriches the possible outcomes for the path of specialization and the production composition in steady state within the neoclassical framework. Moreover, the presence of natural resources increases the possible pattern of convergence, since the economy can reach alternative steady-state equilibria characterized by different capital-labor ratios and levels of consumption per worker.

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Appendix: Figures

Figure 1: Phase Diagram without Natural Resources: The Steady State under Complete Diversification

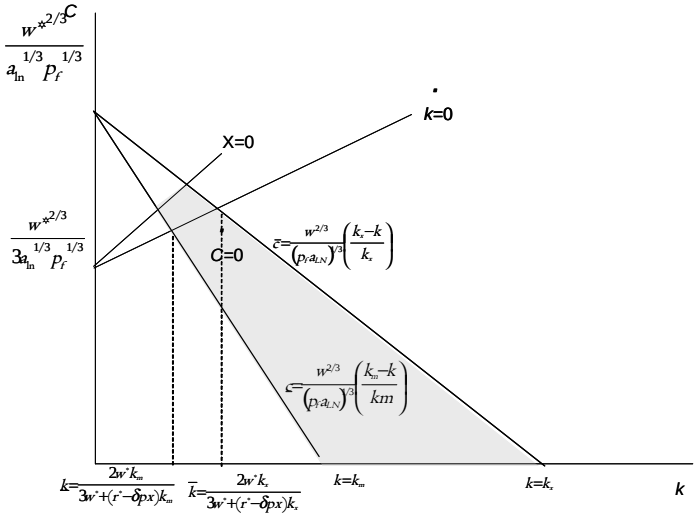
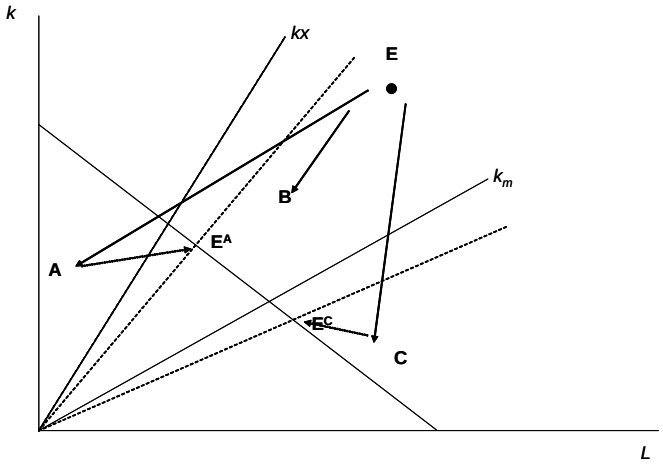


Figure 2: Diversification Cones Net of Natural Resources



E: Initial endowment, excluding labor used in the non-tradable sector.

Figure 3: Phase diagram with Natural Resources. The transition and the steady state

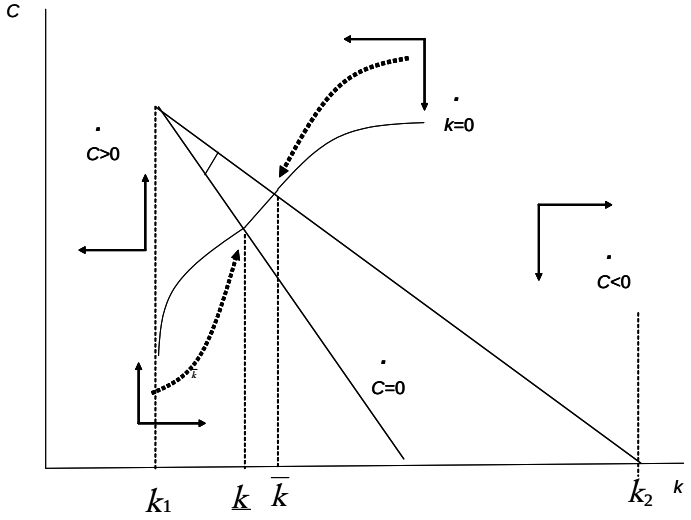


Figure 4: Complete diversification with Natural Resources: Case 1 ($k_f > k_x > k_m$)

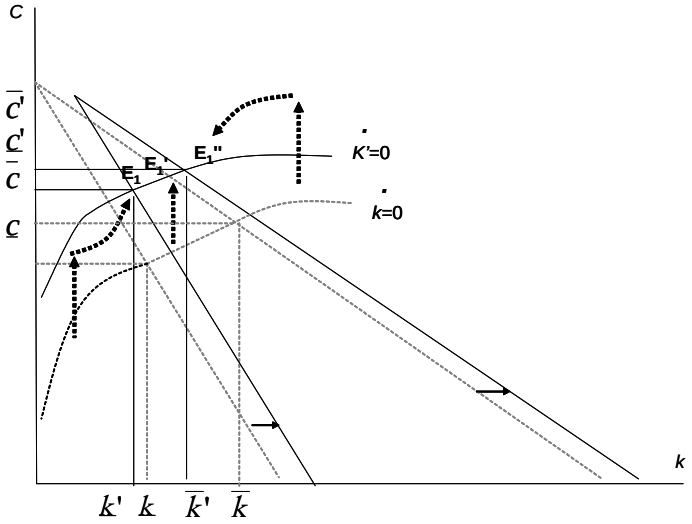


Figure 5:

Figure 6: Complete Diversification with Natural Resources: Case 2 ($k_x > k_f > k_m$)

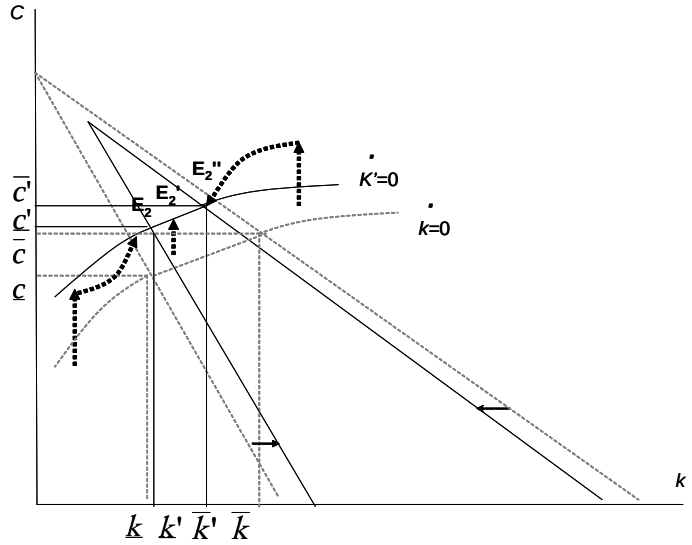
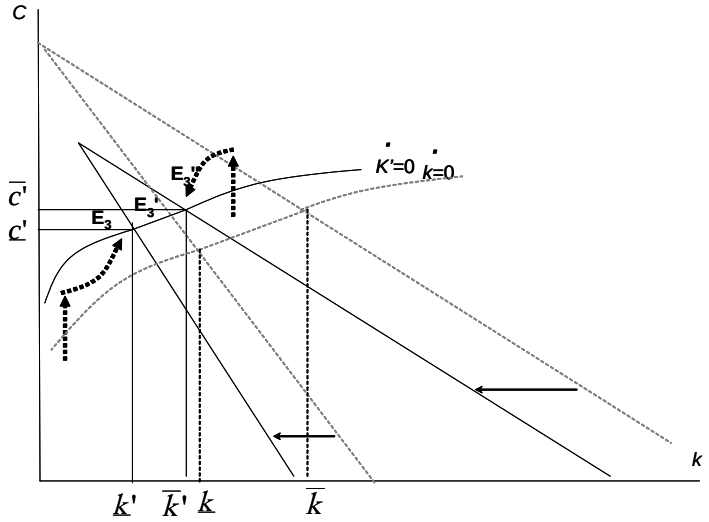


Figure 7: Complete Diversification with Natural Resources: Case 3 ($k_x > k_m > k_f$)



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