MQiTE WORKING PAPER SERIES

WP # 12-14

Neoclassical Growth and the Natural Resource Curse Puzzle

María Dolores Guilló and Fidel Pérez-Sebastián

Universitat d'Alacant

Neoclassical Growth and the Natural Resource Curse Puzzle

María Dolores Guilló* guillo@ua.es

Fidel Perez-Sebastian* fidel.perez@ua.es

June 2012

Abstract

The traditional view that natural riches increase the wealth of nations has been recently challenged by empirical findings that point out that natural inputs are negatively related to growth. This paper shows, within a two-sector neoclassical growth model with international trade in goods, that these two views can be reconciled. Natural inputs directly affect both long-run income and transitional growth. These two effects can be positive or negative depending on input elasticities. Furthermore, they go in opposite directions, creating a tension that complicates the interpretation of estimated-coefficient signs in growth regressions. Quantitative results show that the two effects can be significant.

Key words: neoclassical growth, resource curse, convergence.
JEL Classification: O11, O13, O41, F11, F43.

*Guilló: Department of Economics and IUDESP, Perez-Sebastian: Department of Economics, Universidad de Alicante. Postal address: Universidad de Alicante, Campus de San Vicente, E-03080 Alicante, Spain. We thank Jaime Alonso-Carrera, Francesco Caselli, Oded Galor, Delfim Gomes Neto, Rachel Ngai, Xavier Raurich, Diego Restuccia, Pierre Sartre, David Weil, and seminar participants at the University of Barcelona, Brown University, the Richmond Fed, the University of Vigo, and the 2007 SED meeting in Prague for helpful comments. This research was partially supported by the Spanish Ministry of Science and Technology, SEJ 2007-62656, FEDER funds, and by the Instituto Valenciano de Investigaciones Económicas.

1 Introduction

The effect of natural resources on the wealth of nations is controversial. Traditionally, the discovery of natural riches has been perceived as beneficial for the economy (e.g., see Smith 1776, Malthus 1798, and Schultz 1967). However, recent papers such as Gylfason (2001) and Sachs and Warner (2001) argue that resource abundant countries grow more slowly and lag, on average, behind countries with less resources. This puzzling phenomenon has been labeled as the *natural resource curse*.

Frankel (2010) and van der Ploeg (2011) summarize the literature, pointing out to two main explanations. First, sectors that are intensive in natural resources could be dead-end activities because of, for example, the high volatility and secular decline of the international prices of these commodities. The dead-end nature can be also a consequence of a crowding out effect on other activities such as manufacturing that potentially contribute more intensively to technological change. Second, political considerations. In particular, natural riches can offer an easy source of wealth for politicians and powerful elites, leading to the establishment of bad institutions, and frequent wars for their control.

In this paper, we advance a new explanation based on a simple open-economy two-sector neoclassical growth model. This novel theory can reconcile the two views: natural riches can be beneficial for long-run per capita income but harmful for growth. The key is the existence of differences in input elasticities between the two-sectors that allow the effect of resources evolve along with the economy, rather than being a simple fixed total factor productivity effect.

More specifically, we introduce the natural input into a dynamic Heckscher-Ohlin model of international trade and growth. The economy is composed of a large number of small open economies. Each country has the production structure of the two-sector neoclassical growth model with two goods that are traded internationally. The two sectors employ a natural resource, capital and labor, and have different input intensities. Unlike capital and labor, the potential supply of the natural input is fixed. All nations posses identical preferences and production technologies, but they may differ regarding the natural endowment. Some countries, the developed world, have already reached the steady state, while other countries begin to develop.

The theoretical model offers several interesting results. First, in diversified small-open economies that take the relative price of goods as given by international markets, the natural input affects economic growth through the convergence speed. The reason is that, under those conditions, the economy-wide capital elasticity is affected by the allocation of resources between sectors. In particular, the capital elasticity at the economy level rises (declines) with the natural endowment when the sector that uses it more intensively is also more (less) capital intensive. But if the capital elasticity rises, the interest rate falls more slowly towards its long-run value, thus decreasing the investment rate in capital accumulation, and therefore, the rate of economic growth.

Second, larger stocks of natural inputs can have positive or negative effects on long-run income, depending, again, on input elasticities and trade patterns. A larger natural endowment leads to higher long-run income levels if the natural-resource intensive activity is the less labor intensive. However, if it is relatively labor intensive, a larger natural stock has such a negative influence on capital accumulation that leads the small-open economy that diversifies production to permanently lower levels of income. Interestingly, in all cases, steady-state consumption and, therefore, welfare increase with non-human resources.

Importantly, the long-run and transitional effects run in opposite directions. Depending on input shares, a different natural endowment may bring a larger steady-state income level along with a lower speed of convergence or *vice versa*. This creates a tension that can make natural resources show up in the data as a curse for economic growth even when they positively affect steady-state output. Whether this negative effect appears depends on how far the economy is from the steady state. Economies that are further away have a higher chance of delivering that natural resources are a curse for economic growth.

We perform a quantitative exercise to assess the theory, and show that these effects can be significant. For this purpose we focus on land, and on coal, oil and gas, which are among the most important natural resources that suffers from the puzzling evidence.[1] In the calibrated economy, when the natural endowment triples, income per capita can increase up to a 20%, and the convergence speed fall to less than one third.

The rest of the paper is organized as follows. Section 2 carries out a review of the related literature. The model's economic environment is described in section 3. Section 4 analyzes the impact of natural inputs on a small-open developing nation. A numerical exploration of the model is contained in section 5. Section 6 concludes.

[1] See next section.

2 Review of the Related Literature

Frankel (2010) and van der Ploeg (2011), among others, provides a detailed review of the evidence and theories on the natural resource curse. This section focuses on some papers that offer observational evidence that establishes the puzzle, and reviews the literature that we believe is closer to our research.

Sachs and Warner (1999, 2001) are among the most important works that provide evidence. In particular, they show that their measure of natural resources, and in particular, the share of exports of primary products on GDP displays a negative correlation with posterior growth after controlling for several variables that include economic, geographical, and climate proxies. Their result is illustrated in Figure 1. We observe that nations with lower shares of primary-product exports in 1970 generate, on average, faster GDP per-capita growth from 1970 to 1989. They find that this negative correlation is significant at the 5% level.

Figure 1: Growth and natural resource abundance 1970-1989

Location of Figure 1

The result holds employing a variety of measures of resource abundance. Doppelhofer *et al.* (2004), for example, find that land area divided by population is among the most robust determinants of economic growth, with a negative impact. Isham *et al.* (2005) obtain evidence that oil, minerals such as copper and diamonds, and plantation crops such as coffee and cocoa are negatively related with institutional quality measures that are, in turn, strongly associated to economic growth.

There exist several theoretical explanations for the puzzle. On the political economy side, Hodler (2006) and Caselli (2006), among others, offer frameworks in which a natural resource curse can appear via internal struggle for ownership. Changes in international prices are the channel emphasized by the extensive literature on immiserizing growth or on the structural problems arising from a discovery of a natural resource (the called 'Dutch disease'). Eaton (1992) and Edwards and Van Wijnbergen (1992), for example, show that negative effects on income can occur when either the terms of trade deteriorate or the real exchange rate worsens.

In other models, natural resources disincentive the accumulation of capital inputs necessary to foster economic growth. Matsuyama (1992), for example, considers that the manufacturing sector is characterized by learning by doing that promotes growth, while the primary sector that uses natural resources is a stagnant activity. Adamopoulos (2008) and Galor *et al.* (2008) emphasize that land-ownership inequality can delay industrialization through its effect on the import of intermediate goods used in industry and the implementation of human-capital promoting institutions, respectively. Gylfason (2001) argues that natural riches may develop a false sense of security and harm human capital accumulation.

The evidence is, however, far from being conclusive. As Frankel writes "It is clear that some resource-rich countries do surprisingly poorly economically, while others do well. ... countries such as Norway, Botswana and Chile that have done very well with their endowments (oil, diamonds and copper, respectively) versus others such as Sudan, Bolivia and Congo that have done less well." Other examples are Mehlum *et al.* (2006) and Alexeev and Conrad (2009). The former provides evidence that in nations with good (bad) institutions natural inputs are a blessing (curse) for economic growth.[2] The latter paper, in turn, finds that natural inputs have a positive effect on income per capita.

In addition, some evidence that gives support to the curse is difficult to explain with existing theories. Papyrakis and Gerlagh (2007), for example, find that there is a statistically significant negative relationship between resource abundance and economic growth for 49 US states. It is unlikely that Dutch disease elements, or institutional and political system differences are behind the result.

This justifies the need for other theories that do not rely on the above mechanisms. In our framework, final-goods prices remain constant, total factor productivity growth can be the same across activities, and political institutions are absent. Our focus is, unlike previous theories, on effects that are a consequence of *Rybczynski-type* channels.

The paper is also related to the literature on the importance of the primary sector in shaping economic development and growth. Traditional theories of structural change emphasize two main forces that induce movements of resources across sectors along the development path: sector-biased technical change (Ngai and Pissarides 2007), and non-homothetic preferences (Konsamut *et al.* 2001).[3] Our paper pro-

[2] Acosta (2009) provides a brilliant and well documented description of how the abundance of natural resources in Ecuador has been a curse to economic development and a threat to democracy.

[3] These mechanisms are exploited by other papers such as Galor and Weil (2000), Caselli and Coleman (2001), Kögel and Prskawetz (2001), Hansen and Prescott (2002), Irz and Roe (2005), Gollin *et al.* (2007), Restuccia *et al.* (2008) and Strulik and Weisdorf (2008) to show how agriculture affects

poses a third mechanism that generates resource reallocations, differences in input elasticities across sectors, and shows that it can be potentially important.

Finally, multi-sector models of international trade and growth include Ventura (1997), Mountford (1998), Atkeson and Kehoe (2000), Bajona and Kehoe (2006, 2010), Galor and Mountford (2006, 2008), and Guilló and Perez-Sebastian (2007). We share with them that the main results are driven by the flow of resources across domestic sectors. Unlike us, the first three use more or less standard versions of the two-sector neoclassical framework that do not include natural resources. Neither do Galor and Mountford (2006, 2008), which focus on the fertility and human capital dimensions. Guilló and Perez-Sebastian (2007) present a similar model, but only study the effects of fixed sector-specific inputs on steady-state income.

3 The Environment

Consider a world economy consisting of a large number of small open economies that differ only in their per-capita natural resource endowments and level of development. There are two goods and three inputs of production. The production of the primary and non-primary goods needs capital, labor, and natural inputs, which can freely move across sectors.[4] There is free trade in goods, but international movements of inputs are prohibited.[5] All markets are perfectly competitive. The total stock of the natural input in the economy is non-reproducible. Moreover, we assume for simplicity that its supply is fixed over time, and equal to N.[6] Population grows at a common

the industrialization-process take-off, and helps explain cross-country differences in productivity and income.

[4]Natural resources employed in the primary and non-primary sectors might be thought as not necessarily having the same nature. In this sense, the natural input could be considered as a specific factor in each sector, or an input used exclusively by the primary activity. This would not change the basic results of the paper. This conclusion can be extracted from a previous version of our paper. More specifically, in Guillo and Perez-Sebastian (2005), we employ a setup that differs from the current one only in that the two goods are a consumption product and an investment good, and the natural resource is specific to the production of the former. This previous version obtains effects that are qualitatively the same and quantitatively very similar to the ones obtained now.

[5]Not all non-primary goods are tradable. For example, the scale of trade in services is smaller than in manufacturing. Appendix B shows, however, that this assumption should not have a big impact on our results.

[6]Some natural inputs such as land, large bodies of water, and renewed forests fulfill well this feature. Others, like oil, gas and minerals, are not produced but depreciate in the sense that they are depleted systematically. For these other natural inputs to be in fixed supply, their extraction level had to be constant. We assume this hereafter.

constant gross rate G_L in all countries.[7]

Infinitely-lived households discount future utility with the factor ρ. All household members possess identical preferences defined only over consumption of primary (c_{at}) and non-primary (c_{mt}) goods. In particular, their preferences are given by

$$\sum_{t=0}^{\infty} \rho^t L_t \left[\varphi \ln c_{at} + (1-\varphi) \ln c_{mt}\right], \quad \rho, \varphi \in (0,1), \quad 0 < \rho G_L < 1. \tag{1}$$

Individuals offer labor services and rent capital and natural resources to firms. The stock N is uniformly distributed across all individuals. Since in each period international trade must be balanced, consumers in each household face the following budget constraint

$$c_{at} + p_t(c_{mt} + x_t) = r_{kt}k_t + r_{nt}n_t + w_t, \tag{2}$$

where the evolution of capital per worker is governed by

$$G_L k_{t+1} = (1-\delta)\, k_t + x_t. \tag{3}$$

In the above expressions, x_t is the per capita demand of non-primary goods used for investment, whose price is p_t; r_{kt}, r_{nt}, and w_t are, respectively, the rental rates on capital, natural resources, and labor; n_t and k_t denote the amount of the natural input and capital owned by the individual at date t, respectively.[8] The primary good is the numeraire.

Households in each country will maximize (1) subject to (2) and (3), taking as given the world output prices and the domestic rental rates for production factors. Consumption will be split between the two goods according to

$$\frac{c_{at}}{c_{mt}} = \left(\frac{\varphi}{1-\varphi}\right) p_t. \tag{4}$$

In addition, the Euler equation corresponding to this dynamic programing problem is

$$\frac{c_{t+1}}{c_t} = \frac{p_{t+1}}{p_t} \rho \left(\frac{r_{kt+1}}{p_{t+1}} + 1 - \delta\right), \tag{5}$$

[7] Galor and Weil (1999, 2000) and Ashraf and Galor (2008) show that Malthusian population dynamics can have important effects on economic growth and development. It can then be argued that Malthusian forces could as well equalize the ratio of natural inputs to labor across nations. This however would be possible only over very long horizons. As Gallup *et al.* (1999) show, the distribution of population around the world varies enormously, depends mainly on geographical features, and was heavily influenced by demographic trends well before the period of modern economic growth.

[8] In the model, variables in per-capita terms and in per-worker terms coincide.

where $c_t = c_{at} + p_t c_{mt}$ is total aggregate consumption per capita. Equation (5) is standard. It says that the growth rate of consumption depends on the present-utility value of the rate of return to saving. This return reflects that giving up a unit of present consumption allows buying $1/p_t$ units of the investment good today that, after contributing to the production process, will covert themselves tomorrow in $(1 + r_{kt+1}/p_{t+1} - \delta)$ units that can be sold at a price p_{t+1}.[9]

In each nation, production of the primary good (Y_{at}) is given by

$$Y_{at} = AE_{at}^{1-\alpha} K_{at}^{\alpha} N_{at}^{\beta} L_{at}^{1-\alpha-\beta} = AE_{at}^{1-\alpha} L_{at} k_{at}^{\alpha} n_{at}^{\beta}, \quad \alpha,\, \beta, \alpha{+}\beta \in (0, 1)\,. \tag{6}$$

And the production of non-primary (Y_{mt}) by

$$Y_{mt} = BE_{mt}^{1-\theta} K_{mt}^{\theta} N_{mt}^{\gamma} L_{mt}^{1-\theta-\gamma} = BE_{mt}^{1-\theta} L_{mt} E_t k_{mt}^{\theta} n_{mt}^{\gamma}, \quad \theta, \gamma, \theta{+}\gamma \in (0, 1)\,. \tag{7}$$

In the above expressions K_{it}, L_{it} and N_{it} denote, respectively, the amount of capital, labor and natural resource devoted in period t to the production of good i, and $k_{it} = K_{it}/L_{it}$ and $n_{it} = N_{it}/L_{it}$ their relative use, for $i = a, m$. E_{it} stands for the efficiency level in sector i at period t that grows at a common exogenous gross rate $G_{E_i} \geq 1$ in all countries. We shall assume that sectoral efficiency levels are initially the same, $E_{a0} = E_{m0} = E$, although E can differ across countries. A and B are constant positive efficiency parameters common to all countries.

Let us denote the labor share in the production of good i by $l_{it} = L_{it}/L_t$. Notice that because consumers are alike, the amount of capital owned by each individual will equal the country's capital-labor ratio. Hence, the constraints on labor, capital, and the natural input within a country can be written as follows:

$$l_{at} + l_{mt} = 1, \tag{8}$$

$$l_{at} k_{at} + l_{mt} k_{mt} = k_t, \tag{9}$$

$$l_{at} n_{at} + l_{mt} n_{mt} = n_t. \tag{10}$$

Firms in each country will maximize profits taking as given world prices and the domestic rental rates on production factors. From the production functions (6) and

[9] We could introduce a minimum consumption level of primary goods in household's preferences, expression (1). In fact, minimum consumption can make the natural input affect positively transitional growth at early stages of the adjustment process, as Irz and Roe (2005) show. This survival consumption requirement would not, however, affect our results. The reason is that its effect disappears asymptotically as the economy approaches the steady state. Therefore, it should have a negligible impact on steady-state outcomes and on the asymptotic speed of convergence.

(7), production efficiency implies that

$$
\begin{aligned}
r_{kt} &= \alpha A E_{at}^{1-\alpha} k_{at}^{\alpha-1} n_{at}^{\beta} = p_t \theta B E_{mt}^{1-\theta} k_{mt}^{\theta-1} n_{mt}^{\gamma}, &(11)\\
r_{nt} &= \beta A E_{at}^{1-\alpha} k_{at}^{\alpha} n_{at}^{\beta-1} = p_t \gamma B E_{mt}^{1-\theta} k_{mt}^{\theta} n_{mt}^{\gamma-1}, &(12)\\
w_t &= (1-\alpha-\beta) A E_{at}^{1-\alpha} k_{at}^{\alpha} n_{at}^{\beta} = p_t (1-\theta-\gamma) B E_{mt}^{1-\theta} k_{mt}^{\theta} n_{mt}^{\gamma}. &(13)
\end{aligned}
$$

Of course, these equalities will hold only for the technologies that are used in equilibrium. The following proposition establishes the firms that open in equilibrium.[10]

Proposition 1 *Domestic firms will enter the market of non-primary goods if*

$$p_t > \frac{A}{B} \frac{E_{at}^{1-\alpha}}{E_{mt}^{1-\theta}} \left(\frac{\alpha}{\theta}\right)^{\theta} \left(\frac{\beta}{\gamma}\right)^{\gamma} \left(\frac{1-\alpha-\beta}{1-\theta-\gamma}\right)^{1-\theta-\gamma} n_t^{\beta-\gamma} k_t^{\alpha-\theta}. \tag{14}$$

And no firm will enter the market of primary goods if

$$p_t \geq \frac{A}{B} \frac{E_{at}^{1-\alpha}}{E_{mt}^{1-\theta}} \left(\frac{\alpha}{\theta}\right)^{\alpha} \left(\frac{\beta}{\gamma}\right)^{\beta} \left(\frac{1-\alpha-\beta}{1-\theta-\gamma}\right)^{1-\alpha-\beta} n_t^{\beta-\gamma} k_t^{\alpha-\theta}. \tag{15}$$

The right side of expression (14) determines a minimum price above which it becomes profitable for the producers of non-primary products to enter the market. This minimum price depends on the relative natural endowment, the stock of capital per capita, the sector productivities and the factor intensities. Let us denote it by $p^{\min}(k_t; n_t, E_{at}, E_{mt})$. A small open economy then specializes in a-products if $p^{\min}(k_t; n_t, E_{at}, E_{mt})$ is greater than or equal to the international price p_t. More specifically, if the production of primary goods is more natural-input intensive, closing the non-primary sector becomes more appealing as n_t increases and as p_t declines or, in other words, as the primary-goods activity becomes relatively more productive for given k_t. In addition, if this activity is more capital intensive than the non-primary one, larger values of k_t have the same effect as larger stocks of n_t. The right side of the second inequality, expression (15), determines a maximum price above which it is not profitable to allocate any resources into the primary sector; let us denote it by $p^{\max}(k_t; n_t, E_{at}, E_{mt})$. The interpretation of this second condition follows the same logic as the one of condition (14).

Furthermore, notice that $p^{\min}(k_{at}; n_{at}, E_{at}, E_{mt}) = p^{\max}(k_{mt}; n_{mt}, E_{at}, E_{mt})$ under diversification, and that this value must equal the international price level p_t at every

[10] The proofs of the propositions presented in the paper are in appendix A.

point in time t for the market-equilibrium zero-profit condition to hold, a property that will prove helpful in our analysis.

From the firms' optimality conditions, we can derive expressions for input intensities in each sector under diversified production. Define the relative factor price $\omega_{kt} = w_t/r_{kt}$. The efficiency conditions in production (11) and (13) determine the optimal allocations of capital as a function of this relative factor price:

$$k_{mt} = \left(\frac{\theta}{1-\theta-\gamma}\right)\omega_{kt}, \tag{16}$$

$$k_{at} = \left(\frac{\alpha}{1-\alpha-\beta}\right)\omega_{kt}, \tag{17}$$

It follows from (16) and (17) that primary goods will be more capital-labor intensive if and only if $\theta(1-\beta) < \alpha(1-\gamma)$. Similarly, defining the relative factor price $\omega_{nt} = w_t/r_{nt}$, (12) and (13) yield that

$$n_{mt} = \left(\frac{\gamma}{1-\theta-\gamma}\right)\omega_{nt}, \tag{18}$$

$$n_{at} = \left(\frac{\beta}{1-\alpha-\beta}\right)\omega_{nt}. \tag{19}$$

These two expressions imply that the production of primary goods will be more N-labor intensive than the production in the non-primary sector if and only if $\beta(1-\theta) > \gamma(1-\alpha)$.[11]

From equations (8), (9), (16) and (17), we can write

$$k_t = k_{mt}\left[(1-l_{mt})\frac{(1-\theta-\gamma)\alpha}{\theta(1-\alpha-\beta)} + l_{mt}\right]. \tag{20}$$

And from expressions (8), (10), (18) and (19),

$$n_t = n_{mt}\left[(1-l_{mt})\frac{(1-\theta-\gamma)\beta}{\gamma(1-\alpha-\beta)} + l_{mt}\right]. \tag{21}$$

It is also possible relating n_{mt} and k_{mt}. In particular, equation (11) implies that

$$n_{mt} = \left[\frac{r_{kt}}{\theta p_t}\left(\frac{k_{mt}}{E_{mt}}\right)^{1-\theta}\right]^{1/\gamma}. \tag{22}$$

Another interesting variable is aggregate per capita output, defined as a weighted sum of primary- and non–primary-goods production,

$$y_t = l_{at}y_{at} + p_t l_{mt} y_{mt}. \tag{23}$$

[11] N-labor stands for the ratio of the natural input to labor.

Using expressions (6) to (8), (13) and (23) we can write a nation's GDP level per capita under diversified production as

$$y_t = \frac{w_t}{1-\alpha-\beta}\left[1 + l_{mt}\left(\frac{\theta+\gamma-\alpha-\beta}{1-\theta-\gamma}\right)\right]. \tag{24}$$

It is interesting to note that the economy's GDP can decrease with a larger allocation of labor into the production of primary goods if this activity is more labor intensive than the non-primary sector.

Before finishing this section, let us briefly describe the steady-state equilibrium path. Over there, the employment of the natural input in each sector, the labor shares and the rental price of capital will remain invariant, and the rest of variables will grow at constant rates. Denote by an asterisk ($*$) steady-state outcomes, then the consumers' optimality condition (5) implies

$$\frac{r^*_{kt}}{p^*_t} = G^*_k \rho^{-1} + \delta - 1; \tag{25}$$

where G_i represents the gross rate of growth of variable i. Here we have used the result that $G^*_c / G^*_p = G^*_k$.[12]

4 The Developing Small-Open Economy

Suppose that all but one of the countries that compose our economy are identical in all aspects and have already reached the steady-state. We can think of this group of nations as the developed world.[13] The equilibrium value of the relative price of goods, p^*_t, will be pinned down by this developed world, and will not be affected by the behavior of the small (still developing) country.[14] We shall assume throughout that the natural input share in the primary sector is larger than in the non-primary sector, that is, $\beta > \gamma$.

Consider the small nation with an initial capital stock such that it is still moving along its adjustment path. It faces the steady-state relative output price $p_t = p^*_t$ for all t. Substituting this price in equations (2) to (13), we obtain the equation system that characterizes the late-blooming nation's dynamics. It can be easily shown that the developing economy will accumulate capital until its rental rate falls down to

[12] Steady state growth rates for the different variables are given in appendix A.

[13] A full description of the behavior of the developed world is provided in appendix A.

[14] The international relative price of final goods is derived in the appendix, and given in equation (40).

the world's rate r^*_{kt}, which is by equation (25) exclusively determined by consumers' preferences and p^*_t, and that its pattern of production along the adjustment will follow from Proposition 1. However, evaluating the impact of the natural input on growth along this transitional process requires the use of numerical methods; the next section carries out this numerical exercise. Here, we focus on the steady-state scenario, which can be studied analytically.[15]

From now on, the asterisk ($*$) denotes the international diversified-production equilibrium for the world economy, which is not affected by a small-open economy's behavior, whereas the superscript (^{ss}) denotes the steady state values for the less developed country. Expressions (14) and (15) determine the threshold levels for the capital stock that define the small economy's diversification interval for given p^*_t, n_t and the sector efficiency levels. Consider, first, the case of a late-bloomer that ends its development path diversifying production. Given that $r^{ss}_{kt} = r^*_{kt}$, equations (11) to (13), (22) and (25) imply that the long-run (sector-efficiency-adjusted) capital-labor ratio in non-primary goods will equal the one of the world economy, $k^{ss}_{mt}/E_{mt} = k^*_{mt}/E^*_{mt}$. This is all you need to guarantee in the long run that the same will be true for primary goods, $k^{ss}_{at}/E_{at} = k^*_{at}/E^*_{at}$, that (sector-efficiency-adjusted) factor-price equalization holds, $w^{ss}_t/E_{it} = w^*_t/E^*_{it}$ and $r^{ss}_{nt}/E_{it} = r^*_{nt}/E^*_{it}$ for $i = a, m$, and that the country will be using the same N-labor ratios as the rest of the world, $n^{ss}_{at} = n^*_{at}$ and $n^{ss}_{mt} = n^*_{mt}$.

The difference with the world economy will come regarding the labor allocations and the overall capital stock of the developing nation. The labor share in the primary sector l^{ss}_a will always rise with the natural endowment since we assume that this sector is more natural resource intensive. The stock of capital per worker k^{ss}_t, in turn, will increase with n_t if primary goods are more capital intensive; it will fall with n_t otherwise. To see this, notice that at the steady state $k^{ss}_t = l^{ss}_a k^*_{at} E_{at}/E^*_{at} + (1 - l^{ss}_a) k^*_{mt} E_{mt}/E^*_{mt}$, and that $k^*_{at} E_{at}/E^*_{at}$ and $k^*_{mt} E_{mt}/E^*_{mt}$ are exogenous constants to the small open economy and do not depend on its natural endowment.

As a result, the effect of an increase in the natural resource on long-run income can be also positive or negative. From the economy's demand-side point of view, income per worker can be written as $y^{ss}_t = w^*_t E/E^* + r^*_{kt} k^{ss}_t + r^*_{nt} E/E^* n_t$. In this expression,

[15] Atkeson and Kehoe (2000) show that, in the standard dynamic Heckscher-Ohlin model, a country that starts developing later than the world economy remains permanently poorer. Guillo and Perez-Sebastian (2008), however, prove that this is not the case when inputs in fixed supply are present.

natural input rents always rise with n_t.[16] However, arguments above imply that the steady-state capital and, then, interest payments can go up or down. As equality (24) says, the consequence is that whether or not y_t^{ss} rises depends ultimately on inputs' elasticities. More specifically, a larger N-labor endowment of the small developing economy will have a positive effect on long-run per capita income if the production of primary goods is less labor intensive than in non-primary goods, otherwise larger values of n_t will be associated to smaller values of y_t^{ss}.

From the economy's production side, the forces that lead to this finding are the following. On the one hand, more natural riches increase the productivity of all inputs; this is good for income. On the other, the increase in the fixed factor reallocates capital and labor from the rest of the economy to the sector that is more N-labor intensive. In a small-open economy for which the world's relative price is given, the latter *Rybczynski effect* implied by the augmented factor can reverse the positive productivity effect, and generate a lower long-run per capita income when primary goods are less capital intensive.

Consider now the scenario of long-run specialization, which has also interesting implications. Proposition 1 implies that specialization in primary goods will occur in the long run whenever $n_t \geq n_{at}^*$. In that case, income per capita is given by $y_t^{ss} = AE_{at}^{1-\alpha} \left(k_t^{ss}\right)^{\alpha} n_t^{\beta}$, with $k_t^{ss} = k_{at}^* \left(n_t/n_{at}^*\right)^{\beta/(1-\alpha)} E/E^*$, which follows from the equalization of interest rates, $r_{kt}^{ss} = r_{kt}^*$. This proposition also says that long run specialization in non-primary production will happen whenever $n_t \leq n_{m_t}^*$, which implies a steady state income equal to $y_t^{ss} = p_t^* BE_{mt}^{1-\theta} \left(k_t^{ss}\right)^{\theta} n_t^{\gamma}$, with $k_t^{ss} = k_{mt}^* \left(n_t/n_{m_t}^*\right)^{\gamma/(1-\theta)} E/E^*$. Therefore, in either case income increases with the natural endowment. Moreover, long run income can be above the world's average if n_t is sufficiently large.

The next proposition summarizes these results.

Proposition 2 *Suppose a small open economy that starts its adjustment path with a capital-labor endowment $k_0/E < \min\left\{k_a^*/E^*, k_m^*/E^*\right\}$ and a stock of the natural resource N. (a) At the steady state, it will diversify production if $n_{mt}^* < n_t < n_{at}^*$, it will specialize in the production of $a-$goods if $n_t \geq n_{at}^*$, or in the production of $m-$goods if $n_t \leq n_{mt}^*$. (b) Under diversification, (sector-efficiency adjusted) factor price equalization will hold and the country's income y_t^{ss} will decrease (increase) with*

[16] Balanced trade implies that savings are equal to gross investment at every period, so the relationship between savings and the natural endowment at the steady state is the same as the one between the capital stock and n.

n_t if $\alpha + \beta < (>)\ \theta + \gamma$, y_t^{ss} will not depend on n_t if labor shares across sectors are the same. (c) Under specialization, y_t^{ss} always rises with n_t.

A final remark: findings in this section depend mainly on the small economy assumption, the economy's level of development and openness are secondary driving forces. If economies were open but not small, the steady-state relative price of non-primary goods would be positively related to the natural endowments of the different countries. As a result, the relation between a country's natural endowment and its long-run income could be always positive, even in the diversification cone, provided that the country is relatively large (this is shown in appendix C within a two-country world). On the other hand, it is straightforward that the steady state results would apply to any small-open economy that belongs to the developed world if we consider different N-labor ratios across that group of nations.

5 Income Levels and Convergence Rates

Next, we conduct a numerical experiment to dig deeper on the impact of a country's relative natural endowment on its steady-state level of per capita output and speed of convergence. In this exercise, we focus on two types of natural inputs: land; and coal, oil and gas. As we discuss above, those ones are among the most important natural resources that deliver the puzzling negative effect on economic growth.

We first calibrate the model parameters. After that, steady-state outcomes for a developing nation with respect to the developed-world economy are computed. Finally, we obtain the asymptotic speed of converge for different values of N, which requires a normalized dynamic system. A complete description of this normalization is given in appendix A.

5.1 Calibration

Let us first concentrate on land. Data on arable land is obtained from the Food and Agriculture Organization of the United Nations (FAO) for the period 1967 to 1996. Arable land per capita shows a world's average of 0.80 hectares, and ranges from 0.002 to 6.453. There are, however only 2 out of 97 nations with arable land per capita above 2.3 hectares.[17] For this reason, the experiments consider values of land

[17] These exceptions are Canada and Australia that have an arable land per capita endowment equal to 3.8 and 6.5 hectares, respectively.

between 0.002 and 2.3. We normalize the world average N^* to 1. Then, land of the small open economy N can be thought of as referring to its relative endowment per capita with respect to the world average.[18] Which implies that N goes from 0.002 to 3.

Regarding the production technology parameters we consider alternative measures of the sectoral income shares that are consistent with the overall factor income shares in GDP. Given that the natural input is land, we proxy the primary and non-primary sectors by agriculture and non-agriculture, respectively. Parente and Prescott (2000) report that a share of capital of 0.25, a land share of 0.05, and a labor share of 0.70 are consistent with the U.S. growth experience. Since the average share of Agriculture in US GDP (net of indirect taxes) over the period 1987-2000 is 2 percent, the following restrictions will determine, respectively, alternative measures of the capital and land shares across sectors:

$$0.02\alpha + 0.98\theta = 0.25, \tag{26}$$

$$0.02\beta + 0.98\gamma = 0.05. \tag{27}$$

Information on the contribution of land to agriculture can be obtained from U.S. Department of Agriculture (USDA) Statistics. Focusing on 1997, non-operator landlords' rents amount to 12,833 millions of current dollars (USDA 2000) and Agricultural GDP net of indirect taxes amounts to 123,042 millions of current dollars, which imply a share of land in agricultural output of 0.10; but this is a lower bound because returns from land owned by producers are not included. We can get a broader estimate of the land return in agriculture using data on cropland (excluding idle cropland), grassland pasture and range used from USDA (2006), and average cash rents per acre of cropland and pasture from USDA (2004). Employing these data, revenues from land become 28,457 millions of dollars. This number, in turn, gives a share of land income in agriculture of 0.23. Herrendof and Valentinyi (2008) find a smaller interval of values for this parameter: their estimate is 0.11 when they employ purchaser prices, and 0.18 when they use producer prices. Given that results where qualitatively the same for these different β, we choose $\beta = 0.18$, an intermediate value, as the benchmark. Equation (27) then implies that γ equals 0.047.

With respect to the contribution of capital to agriculture and non-agriculture, evidence is mixed. Recent studies suggest that the former is clearly more capital

[18] We considered arable land, potential arable land, equivalent potential land, and total area as alternative measures of the land input and found negligible differences in the results.

intensive in developed nations. For example, Herrendof and Valentinyi (2008) find that the capital income share in the non-agriculture sector is 0.28, whereas for the agriculture sector is 0.30 if purchaser prices are used and 0.36 if instead producer prices are used. In addition, data from Jorgenson and Stiroh (2000) imply that the average capital share of agriculture in the U.S. economy for the period 1967-1996 is 37.4 percent and 32.8 percent for manufactures plus services. Also, Echevarria (2000) finds a capital share of 43 percent in agriculture for the Canadian economy once the value of land is excluded. Early cross-country studies focusing on the agricultural sector, however, such as Hayami and Ruttan (1985), focusing mainly on developing economies, seem to find smaller capital shares after controlling for the contribution of land. These studies estimate an average share of structures and equipment, which is just a fraction of the capital in agriculture, of around 10 percent.[19]

According with this wide range of estimates, we shall consider the following set of capital shares that belong to three general scenarios that provide important qualitative as well as quantitative differences:

$$(\alpha, \theta) = \{(0.1, 0.253), (0.2, 0.251), (0.25, 0.25), (0.3, 0.28), (0.36, 0.28)\}. \tag{28}$$

To obtain the value of θ in this set, we use restriction (26) for α equal or less than 0.25, and estimates in Herrendof and Valentinyi (2008) for α larger than 0.25..

It follows from the chosen input elasticities that agricultural production is more land intensive than non-agricultural production in all possible cases, and that agricultural production will be more capital intensive when $\alpha \geq 0.25$.

We set the growth rate of per capita output equal to two percent, $G_y = 1.02$, the depreciation rate of capital δ to 0.05, the population growth rate to 1.2 percent. Information on relative output prices is obtained from the Economic Report of the president (2004), Table B67. From there, we equalize G_p^* to 1.01 – the average growth rate of the price index of industrial products relative to farm products for the period 1980-2000 – and fix the steady state (normalized) price to the average price index, $\hat{p}^* = 1.08$. These values of G_y and G_p imply that $G_k = G_y/G_p = 1.0099$.

We still have to give a value to the parameters in the utility function. We set the steady state share of investment in total output equal to the US average for the period

[19] Other authors such as Mundlak *et al.* (1999, 2000) point out that estimates should take into account that capital in agriculture is composed not only of structures and equipment but also of livestock and orchards. Taken both components together, and controlling for the contribution of land, the estimated elasticity of capital in agricultural output by the early studies is between 33 percent and 47 percent.

1987-2000, that is $(G_L G_k + \delta - 1)\, p_t^* k_t^* / y_t^* = 0.21$. This condition, the assumption that the capital income share $r_k^* k_t^* / y_t^*$ is 0.25, and (25) imply a value for the interest rate r_k^*/p^* equal to 0.08, which in turn implies a value for the discount rate ρ equal to 0.98.

With respect to the weight of agricultural-products in consumption, φ, we proceed as follows. Since the U.S. investment share over the period considered was, on average, 0.21, we have that at the steady-state

$$\frac{p_t^* y_{mt}^* l_{mt}^* - p_t^* c_{mt}^*}{y_t^*} = 0.21.$$

Using expression (4) and the market clearing condition for agricultural goods (35), we can rewrite the last equality as

$$\frac{p_t^* y_{mt}^* l_{mt}^*}{y_t^*} - \left(\frac{1-\varphi}{\varphi}\right) \frac{y_{at}^* l_{at}^*}{y_t^*} = 0.98 - \left(\frac{1-\varphi}{\varphi}\right) 0.02 = 0.21. \tag{29}$$

This assigns a value of 0.025 to φ. Notice that higher weights of agriculture in total output will be associated with larger values of this parameter. Finally, in all parameter specifications we set the production efficiency parameter B equal to one and solve for the value of the production parameter A that is consistent with the value of $\hat{p}^*$ given above.

A similar parametrization of the model is obtained if we consider coal, oil and gas as the natural input. To obtain the range of N for this case, we look at BP (2010). BP reports proven reserves of these natural riches. Normalizing to 1 the ones of North America, reserves at the end of 2009 of coal go from 0.01 in the Middle East to 1.11 in Europe; gas from 0.88 in South and Central America to 8.32 in the Middle East; and Oil from 0.58 in the Asia-Pacific region to 10.29 in the Middle East. Given that, we impose intermediate upper and lower bounds of 0.6 and 8 for N in the case of energy resources.

The primary sector is now composed of their respective extraction sectors. To obtain production shares, we use the sectoral input-output database described in Jogerson and Stiroh (2000).[20] In our model the output of the primary activity is not employed as an input in the non-primary one, so we have to exclude petroleum and gas products plus gas utilities to obtain the non-primary sector. It follows then from

[20] On line as Dale W. Jorgenson, 2007-09-22, "35 Sector KLEM", hdl:1902.1/10684 UNF:3:TqM00zRqsatX2q/teT253Q== V1 [Version].

Figure 2: Long-run income (LHS panels) and consumption (RHS panels) relative to the developed world average as a function of land

Location of Figure 2.

the data considered that the primary sector represents 0.025 of the total value added of the model economy.

In order to give values to the shares of the natural input in output production, we employ energy shares. This approximation reflects that petroleum, coal and gas represent about 87% of the energy consumption in the world (see for example Wikipedia). The values of α and β go from 0.26 and 0.16 in the coal sector to 0.65 and 0.10 in the fuel and gas extraction sector, respectively. We set as intermediate values $\alpha = \{0.4, 0.5\}$ and $\beta = 0.13$. With respect to the income shares in the rest of the economy, the average values become $\theta = 0.29$ and $\gamma = 0.04$. In addition, given that point natural resources in their raw form are used almost exclusively in their extracted industries, results are also given for a very small value of the natural input share in the non-primary activity γ of 0.004. Then, the parameter values that vary and define the four cases considered are the following:

$$(\alpha, \gamma) = \{(0.4, 0.04), (0.5, 0.04), (0.4, 0.004), (0.5, 0.004)\}. \tag{30}$$

As above, the information on relative output prices is taken from the Economic Report of the president (2004), Table B67. From there, we equalize G_p^* to 1.014 – the average growth rate of the price index of total industrial products relative to fuels and related products and power for the period 1980-2000 – and fix the steady state (normalized) price to the average price index, $\hat{p}^* = 1.3$. Proceeding as before, the implied values for the rest of the parameters are $G_k = 1.006$, $\varphi = 0.031$, $\rho = 0.93$.

5.2 Quantifying long-run income

Remember expression (24): under diversified production, steady-state income in the small-open economy can grow, fall or remain constant with n, depending on whether the primary sector is less, more, or equally labor intensive than the non-primary activity, respectively. These qualitative results for the land parameterization are illustrated in Figure 2. The Figure depicts the long run income of the small open economy relative to the developed world average y/y^* against the relative land endowment N. In order to compute y/y^*, we employ the relative normalized income

Table 1: Steady-state relative income for different parameterizations

α	θ	β	γ	Land, N					
				0.002	0.95	1.25	1.98	2.5	3
0.10	0.253	0.18	0.047	0.679	1.000	0.997	0.989	0.984	0.978
0.2	0.251	0.18	0.047	0.672	0.998	1.010	1.041	1.063	1.085
0.25	0.25	0.18	0.047	0.677	0.996	1.016	1.064	1.099	1.132
0.3	0.28	0.18	0.047	0.677	0.996	1.016	1.064	1.098	1.131
0.36	0.28	0.18	0.047	0.665	0.994	1.026	1.104	1.159	1.212
				Coal, oil and gas, N					
				0.6	0.95	1.25	1.98	2.5	8
0.40	0.29	0.13	0.04	0.967	0.993	1.031	0.989	1.186	1.615
0.50	0.29	0.13	0.04	0.963	0.991	1.044	1.712	1.264	1.973
0.40	0.29	0.13	0.004	0.992	0.999	1.004	1.019	1.029	1.136
0.50	0.29	0.13	0.004	0.988	0.998	1.006	1.027	1.041	1.193

levels $\widehat{y}/\widehat{y}^*$ defined in appendix A. These two ratios coincide when both economies have the same productivity parameters and population levels, $E_{at} = E_{at}^*$, $E_{mt} = E_{mt}^*$ and $L_t = L_t^*$. This is the particular case that we consider.

The Figure shows the diversified production interval between dotted vertical lines in the three cases. Notice that, within this interval, y/y^* is a linear function of land since factor price equalization holds and $l_a = (n_t/n_{at}^* - n_{mt}^*/n_{at}^*) / (1 - n_{mt}^*/n_{at}^*)$. In the top chart of Figure 2, agriculture is less labor intensive and then y/y^* rises with land. In the middle panel, y/y^*remains constant within the diversification interval because agriculture has the same labor share than non-agriculture. Finally, in the bottom chart, y/y^* falls with land under diversification because agriculture is more labor intensive. Outside the diversification interval, the late-bloomer's income equals $AE_{at}^{1-\alpha}n_t^{\beta}k_t^{\alpha}$ if $n_t \geq n_{at}^*$, or $p_t^*BE_{mt}^{1-\theta}n_t^{\gamma}k_t^{\theta}$ if $n_t \leq n_{mt}^*$, in either case relative income is increasing and concave in n_t.

Figure 2 also shows an interesting feature of the model: steady-state consumption always rises with the natural input. So larger amounts of land imply higher long-run welfare even if income levels are smaller. The reason is that larger amounts of n_t imply lower capital levels when agriculture is less capital intensive than non-agriculture, which lowers steady state savings and investment. This effect on in-

Table 2: Speeds of convergence for different parameterizations, percentage

α	θ	β	γ	Land, N				
				0.95	1.25	1.98	2.5	3
0.1	0.253	0.18	0.047	7.64	7.81	8.27	8.65	9.06
0.2	0.251	0.18	0.047	8.69	8.78	8.98	9.12	9.26
0.25	0.25	0.18	0.047	9.09	9.09	9.09	9.09	9.09
0.3	0.28	0.18	0.047	7.98	7.89	7.69	7.57	7.46
0.36	0.28	0.18	0.047	3.74	3.11	2.11	1.65	1.33
				Coal, oil and gas, N				
				0.95	1.25	1.98	2.5	3
0.40	0.29	0.13	0.04	1.58	0.96	0.001	-0.17	-0.38
0.50	0.29	0.13	0.04	-0.019	-0.020	-0.020	-0.020	-0.020
0.40	0.29	0.13	0.004	0.035	0.026	0.013	0.008	0.004
0.50	0.29	0.13	0.004	0.035	0.026	0.014	0.008	0.005

vestment is stronger than the effect on income (which depends ultimately on labor intensities) and as a result steady-state consumption rises. In contrast, when the primary sector is more capital intensive, both income and investment rise with land, but the effect on income is stronger, so steady state consumption also rises.

To get an idea of the predicted income differences implied by the model, Table 1 gives specific values of $\widehat{y}/\widehat{y}^*$ for the land and energy resource calibrations. We see that steady-state income differences among economies that own different land per capita endowments can be substantial, and increase with the capital share in the sector that uses the natural input more intensively. More specifically, for $(\alpha, \theta) = (0.1, 0.253)$, income per capita is 1.44 times larger in an economy with $N = 3$ than in an economy with $N = 0.002$. This difference rises and generates a 1.8 fold when $(\alpha, \theta) = (0.36, 0.28)$.

The coal, oil and gas case gives additional information. Income per capita differences also increase with the natural input share in the non-primary sector. The maximum difference is achieved when $(\alpha, \gamma) = (0.50, 0.04)$, in which case income per capita for $N = 8$ is 2.05 times larger than when $N = 0.6$. When γ falls to 0.004, this ratio becomes 1.21.

5.3 Quantifying the asymptotic speed of convergence

Next, we study the speed of convergence.[21] Table 2 reports the results for different values of N within the diversification interval for the sets of parameters given in (28) and (30). We only focus on the diversification cone because the convergence speed does not depend on N outside it. This is easily deduced from our first interesting finding: the convergence rate is independent of the natural endowment only if, along the adjustment path, the economy transfers resources between two sectors that have the same capital share ($\alpha = \theta = 0.25$). As a consequence, the convergence speed is independent of N in a specialized economy.

Other interesting results in Table 2 are the following. Most predicted values are consistent with convergence rates estimated in the literature, which vary between the 0.4 percent reported by Barro and Sala-i-Martin (1995) and the 10 percent found by Caselli *et al.* (1996). Secondly, when $\alpha > 0.25$ more N generates a lower speed of convergence for given α, and when $\alpha < 0.25$ larger amounts of natural input increase the speed of convergence. Thirdly, relative differences in predicted numbers are significant and tend to rise with α. For example, when (α, θ) equals $(0.36, 0.28)$, the largest speed, 3.74, is 2.81 times larger than the lowest, 1.33. This is a very significant difference, bigger than the 1.18 discrepancy when (α, θ) is $(0.1, 0.253)$, but lower than the 7-fold that occurs when (α, γ) equals $(0.50, 0.004)$ and N goes from 3 to 0.95.

Comparing land and energy resources, we can see that the only significant difference is that the speed is always below 2 percent, and becomes negative in the $\gamma = 0.04$ case for a relative large endowment of coal, oil and gas. A negative speed means that the economy's income per capita level increases monotonically, but diverges from its balanced-growth path.[22]

Let us give some intuition behind these results. As appendix A shows, the sign of the effect of the natural endowment on the speed is the *opposite* to the sign of the response of $\partial r_{kt+1}/\partial k_t$ to changes in N. This response, in turn, depends on two main derivatives: $\partial^2 r_{kt+1}/\delta k_{mt+1}\partial N$ and $\partial^2 k_{mt+1}/\delta k_t \partial N$. The sign of the first one can be positive or negative depending on $\alpha - \theta$, and represents a *capital elasticity*

[21] See appendix A for details. The program was written in Mathematica, and is available from the authors upon request.

[22] This occurs because the stable root delivered by the normalized system becomes almost one for sufficiently large values of N.

effect. More specifically, we know that as the elasticity of capital becomes larger, the return to capital accumulation, that is, the interest rate, falls more slowly along the adjustment path, thus making the speed smaller. In our model, there are two sectors that employ capital. Hence, the *de facto* economy-wide capital elasticity (EWCE) will be affected by the allocation of resources between them. Under perfect competition, the capital elasticity and the capital share coincide. We can then write $EWCE = (\alpha - \theta)\, s_a + \theta$; where s_a represents the share of the primary sector in GDP. The primary activity has a larger natural input intensity. Hence, s_a will tend to rise with N. As a consequence, the EWCE rises (falls) and the speed falls (rises) with N if $\alpha > \theta$ ($\alpha < \theta$); both remain constant if $\alpha = \theta$.

The derivative $\partial^2 k_{mt+1}/\delta k_t \partial N$ can also be positive or negative depending on α and θ, and represents a *capital accumulation effect*. The accumulation of capital in the non-primary sector occurs more slowly (rapidly) as the natural endowment rises when the primary (non-primary) sector is more capital intensive. The accumulation effect then goes in the same direction as the capital elasticity effect described above. As a consequence, the effect of N on the speed is negative if $\alpha > \theta$, and positive when $\alpha < \theta$.

Finally, it is worth noting that the dynamic system of a small open developing nation described by equations (50) and (52) in the appendix can also be used to study the dynamics of a small early-bloomer that differs on the natural endowment and takes the equilibrium sequence of world prices as given. Therefore, all the qualitative results obtained in this section apply to any small open economy, regardless of its level of development.

The conclusion from the quantitative exercise is that natural inputs can have a significant impact on steady-state income and economic growth. Comparing resource-scarce and resource-abundant nations, the natural input can explain up to a 20% increase in long-run per-capita income and more than a 3-fold in the convergence speed.[23]

[23] We have analyzed how results change if some parameter values are modified. In particular, we have considered variations in the growth rate of the productivity parameters and population, in the natural-input elasticity, and in the share of the primary sector in GDP. Importantly, qualitative findings do not change. With respect to the quantitative ones, a rise in the population growth rate generates negligible variations in relative income, and increases in the speed. A decline in the natural-input elasticity in the primary activity reduces the speed, but the effect on long-run relative income is ambiguous. A reduction in the growth rate of non-primary prices G_{p^*} – which can be a consequence of either a fall in the growth rate of E_a or an increase in the one of E_m – produces a rise in the speed of convergence. Finally, as the share of the primary sector in GDP rises, relative income does

6 Conclusion

Motivated by the empirical literature, this paper advances a new theory that can explain the lack of consensus about the effect of natural resource on economic growth. The model is a standard dynamic Heckscher-Ohlin, and delivers interesting results that occur in small-open economies with diversified production that take international output prices as given.

Within this framework, natural resources affect growth through the convergence speed, and also long-run income. The two impacts can be positive or negative depending on input elasticities, go in opposite directions and are quantitatively significant. They are driven by *Rybczynski-type* effects as a consequence of the special nature of natural resources and, in particular, of their non-reproducible supply. Interestingly, natural riches and international trade always raise long-run consumption and, therefore, welfare in the model, even when the economy ends up with lower long-run income.

The numerical exercise has shown that the type of results found by the resource-curse literature are consistent with the model predictions if the primary sector is more capital intensive. In this scenario, natural inputs have a positive impact on long-run income, but diminish the convergence speed. As a consequence, a natural-resource abundant economy will show smaller growth rates if it is located sufficiently far away from its balanced growth path. Importantly, this scenario does not disagree with the available evidence.

Besides providing a novel explanation for the resource-curse puzzle, our results also contribute to better understand the determinants of the speed of convergence. More standard economic growth frameworks such as Barro and Sala-i-Martin (1995) and Ventura (1997) imply that the convergence speed is only affected by "deep" parameters, like the consumption- and input-substitution elasticities or the discount factor. Our work shows that some variables, like natural inputs, can also significantly affect it.

A key implication is that estimated-coefficient signs in growth regressions for variables that can have transitional effects should be interpreted with caution: a negative (positive) coefficient in a growth regression does not necessarily mean that the vari-

not vary much and the speed slightly increases within the diversification cone; in addition, because more economies fall under diversified production, income differences between resource-abundant and resource-scarce economies diminishes.

able has a negative (positive) effect on long-run income. Therefore, the resource-curse evidence provided by Sachs and Warner (2001), among others, does not imply that natural resources do not contribute positively to long-run income.

Clearly, discriminating accurately between the long-run and transitional effects of these type of variables requires better growth regression specifications. We leave this important issue to future research.

A The Model's Mathematical Appendix

Proof of Proposition 1. Since the natural input is in (fixed) positive supply it is always profitable to produce positive amounts of at least one good. Suppose production of agricultural goods is positive. Profits in non-agriculture are equal to

$$\Pi_{mt} = p_t B E_{mt}^{1-\theta} K_{mt}^{\theta} N_{mt}^{\gamma} L_{mt}^{1-\theta-\gamma} - r_{kt} K_{mt} - r_{nt} N_{mt} - w_t L_{mt}.$$

At the maximum, non-primary-production profits are

$$\left(p_t B E_{mt}^{1-\theta}\right)^{\frac{1}{1-\theta-\gamma}} \left(\frac{\theta}{r_{kt}}\right)^{\frac{\theta}{1-\theta-\gamma}} \left(\frac{\gamma}{r_{nt}}\right)^{\frac{\gamma}{1-\theta-\gamma}} B E_{mt}^{1-\theta} L_{mt} \left[(1-\theta-\gamma) - w_t \left(\frac{\left(\frac{r_k}{\theta}\right)^{\theta}\left(\frac{r_{nt}}{\gamma}\right)^{\gamma}}{p_t B E_{mt}^{1-\theta}}\right)^{\frac{1}{1-\theta-\gamma}}\right] \tag{31}$$

So domestic firms will enter the market for non-primary goods if and only if profits are positive:

$$p_t B E_{mt}^{1-\theta} > \left(\frac{w_t}{1-\theta-\gamma}\right)^{1-\theta-\gamma} \left(\frac{r_{kt}}{\theta}\right)^{\theta} \left(\frac{r_{nt}}{\gamma}\right)^{\gamma} \tag{32}$$

Getting the equilibrium prices from the optimality conditions for primary products given in (11), (12) and (13), we obtain expression (14).

Suppose now that production of non-primary goods is positive. Following the same steps, it follows that domestic firms will enter the market of primary products if and only if profits are positive

$$A E_{at}^{1-\alpha} > \left(\frac{w_t}{1-\alpha-\beta}\right)^{1-\alpha-\beta} \left(\frac{r_{kt}}{\alpha}\right)^{\alpha} \left(\frac{r_{nt}}{\beta}\right)^{\beta} \tag{33}$$

Getting the equilibrium prices from the optimality conditions for non-primary production given in (11), (12) and (13), and changing the direction of inequality, we obtain expression (15).

Proof of Proposition 2. Part (a). Define $A_t = E_{at}^{1-\alpha}/E_{mt}^{1-\theta}$. Let $p^{\min}(k_t; n_t, A_t)$ and $p^{\max}(k_t; n_t, A_t)$ represent the right sides of expressions (14) and (15), respectively. In the steady state diversified production equilibrium, $p^{\min}(k_{at}^*; n_{at}^*, A_t^*) = p^{\max}(k_{mt}^*; n_{mt}^*, A_t^*) = p_t^*$, where $n_{at}^* > n_{mt}^*$ by assumption. Let $\underline{k}_t$ and $\overline{k}_t$ be such that $p^{\min}(\underline{k}_t; n_t, A_t) = p_t^*$ and $p^{\max}(\overline{k}_t; n_t, A_t) = p_t^*$, respectively. That is, $\underline{k}_t = k_{at}^* \left(n_{at}^*/n_t\right)^{\frac{\beta-\gamma}{\alpha-\theta}} \left(A_t^*/A_t\right)^{\frac{1}{\alpha-\theta}}$ and $\overline{k}_t = k_{mt}^* \left(n_{mt}^*/n_t\right)^{\frac{\beta-\gamma}{\alpha-\theta}} \left(A_t^*/A_t\right)^{\frac{1}{\alpha-\theta}}$. Note that because $E_{a0} = E_{m0} = E$, $A_t^*/A_t = (E^*/E)^{\theta-\alpha}$. So $\underline{k}_t = k_{at}^* \left(n_{at}^*/n_t\right)^{\frac{\beta-\gamma}{\alpha-\theta}} E/E^*$ and $\overline{k}_t = k_{mt}^* \left(n_{mt}^*/n_t\right)^{\frac{\beta-\gamma}{\alpha-\theta}} E/E^*$. We can consider the following cases:

(I) If $\alpha \geq \theta$,then $k_{at}^* > k_{mt}^*$. The diversification interval is $\left(\overline{k}_t, \underline{k}_t\right)$ when $\alpha > \theta$. When $\alpha = \theta$, the right sides of expressions (14) and (15) do not depend on k; in this case the result follows directly from Proposition 1.

(I.1) $\alpha > \theta$ and $n_t \in (n^*_{mt}, n^*_{at}) \Rightarrow \overline{k}_t/E < k^*_{mt}/E^* < k^*_{at}/E^* < \underline{k}_t/E$. From Proposition 1, and expressions (14) and (15), $l_{a0} > 0$ and $l_{m0} > 0$ if $\overline{k}_0 < k_0 < k^*_{m0}E/E^*$, or $l_{m0} = 1$ ($l_{a0} = 0$) if $k_0 \leq \overline{k}_0 < k^*_{m0}E/E^*$. If at the steady state $l^{ss}_m = 1$, then (11) implies $k^{ss}_t = k^*_{mt}(n_t/n^*_{mt})^{\gamma/(1-\theta)} E/E^*$, but $n_t/n^*_{mt} > 1 \Rightarrow k^{ss}_t > k^*_{mt}E/E^* > \overline{k}_t$, which by proposition 1 would imply $l^{ss}_a = 1$, so $l^{ss}_m = 1$ cannot be optimal. If at the steady state $l^{ss}_m = 0$, then $k^{ss}_t = k^*_{at}(n_t/n^*_{at})^{\beta/(1-\alpha)} E/E^*$, but $n_t/n^*_{at} < 1 \Rightarrow k^{ss}_t < k^*_{at}E/E^* < \underline{k}$, which by proposition 1 would imply $l^{ss}_a = 0$; so $l^{ss}_m = 0$ cannot be optimal. Hence, $l^{ss}_a > 0$ and $l^{ss}_m > 0$ must be optimal. From (11) to (13), (22) and (25) follows that $k^{ss}_{mt} = k^*_{mt}E/E^*$ (see proof of part (b)), and from (16), (17), (18) and (19) that $k^{ss}_{at} = k^*_{at}E/E^*$, $n^{ss}_{it} = n^*_{it}$ $\forall i$ and $k^*_{mt}/E^* < k^{ss}_t/E < k^*_{at}/E^*$.

(I.2) $\alpha > \theta$ and $n_t \geq n^*_{at} \Rightarrow \overline{k}_t < k^*_{mt}E/E^* < \underline{k}_t \leq k^*_{at}E/E^*$ or $\overline{k}_t < \underline{k}_t \leq k^*_{mt}E/E^* < k^*_{at}E/E^*$. So initially $l_{m0} = 1$ if $k_0 \leq \overline{k}_0$; $l_{a0} > 0$ and $l_{m0} > 0$ if $\overline{k}_0 < k_0 < k^*_{0t}E/E^* < \underline{k}_0$, or $\overline{k}_0 < k_0 < \underline{k}_0 < \widetilde{k}^*_m E/E^*$; $l_{a0} = 1$ if $\underline{k}_0 \leq k_0 < k^*_{m0}E/E^*$. As before at the steady $l^{ss}_{mt} = 1$ cannot be optimal; similarly, steady state diversified production, $n^{ss}_{it} = n^*_{it}$ $\forall i$ would imply $n^*_{mt} < n_t < n^*_{at}$ by (8) and (10), which contradicts $n_t \geq n^*_{at}$. So at the steady state $l^{ss}_a = 1$ must be optimal and $k^{ss}_t = k^*_{at}(n_t/n^*_{at})^{\beta/(1-\alpha)} E/E^* \geq k^*_{at}E/E^*$.

(I.3) $\alpha > \theta$ and $n_t \leq n^*_{mt} \Rightarrow k^*_{mt}E/E^* < k^*_{at}E/E^* < \overline{k}_t < \underline{k}_t$ or $k^*_{mt} \leq \overline{k}_t < k^*_{at} < \underline{k}_t$. So, in either case, initially $l_{m0} = 1$ since $k_0 < k^*_{m0}E/E^* < \overline{k}_0$. A steady state $l^{ss}_a > 0$ and $l^{ss}_m > 0$ would imply $n^*_{mt} < n_t < n^*_{at}$, which contradicts $n_t \leq n^*_{mt}$. A steady state $l^{ss}_m = 0$ would imply $k^{ss}_t = k^*_{at}(n_t/n^*_{at})^{\beta/(1-\alpha)} E/E^*$, but $n_t/n^*_{at} < 1 \Rightarrow k^{ss}_t < \underline{k}_t$, so it cannot be optimal. Hence, $l^{ss}_m = 1$ must be optimal and $k^{ss}_t = k^*_{mt}(n_t/n^*_{mt})^{\gamma/(1-\theta)} E/E^* \leq k^*_{mt}E/E^*$.

(II) If $\alpha < \theta$, then $\widetilde{k}^*_m < \widetilde{k}^*_a$ or $k^*_m > k^*_a$. The diversification interval is $(\underline{k}_t, \overline{k}_t)$. The next proof follows the same steps as in (I). **(II.1)** $k^*_{mt} < k^*_{at}$. **(II.1a)** $n_t \in (n^*_{mt}, n^*_{at}) \Longrightarrow \underline{k}_t < k^*_{mt}E/E^* < \overline{k}_t < k^*_{at}E/E^*$ or $\underline{k}_t < k^*_{mt}E/E^* < k^*_{at}E/E^* < \overline{k}_t$ or $k^*_{mt}E/E^* < \underline{k}_t < \overline{k}_t < k^*_{at}E/E^*$ or $k^*_{mt}E/E^* < \underline{k}_t < k^*_{at}E/E^* < \overline{k}_t$. Initially $l_{m0} = 0$ or $l_{m0} > 0$ and $l_{a0} > 0$; at the steady state $l^{ss}_m = 0 \Rightarrow k^{ss}_t < k^*_{at}E/E^*$ and $k^{ss}_t > \underline{k}_t$ since $n^*_{at}/n_t > 1$ and $\frac{\beta-\gamma}{\theta-\alpha} > \frac{\beta}{1-\alpha}$, so $l^{ss}_m = 0$ cannot be optimal; $l^{ss}_m = 1 \Rightarrow k^{ss}_t > k^*_{mt}E/E^*$ and $k^{ss}_t < \overline{k}_t$, so $l^{ss}_m = 1$ cannot be optimal; so $l^{ss}_a > 0$ and $l^{ss}_m > 0$ and $k^*_{at}E/E^* < k^{ss}_t < k^*_{mt}E/E^*$. **(II.1b)** $n_t \geq n^*_{at} \Longrightarrow k^*_{mt}E/E^* < k^*_{at}E/E^* < \underline{k}_t < \overline{k}_t$. Initially $l_{m0} = 0$; at the steady state $l^{ss}_a > 0$ and $l^{ss}_m > 0 \Longrightarrow n_t < n^*_{at}$, which is false; $l^{ss}_m = 1 \Longrightarrow k^*_{mt}E/E^* < k^{ss}_t < \underline{k}_t$, so $l^{ss}_m = 1$ cannot be optimal; $l^{ss}_m = 0$ is optimal and $k^*_{at}E/E^* \leq k^{ss}_t < \underline{k}_t$. **(II.1c)** $n_t \leq n^*_{mt} \Longrightarrow \underline{k}_t < \overline{k}_t < k^*_{mt}E/E^* < k^*_{at}E/E^*$. Initially, $l_{m0} = 0$ or $l_{m0} > 0$ and $l_{a0} > 0$ or $l_{m0} = 1$. At the steady state $l^{ss}_a > 0$ and $l^{ss}_m > 0 \Longrightarrow n_t > n^*_{mt}$, which is false; $l^{ss}_m = 0 \Longrightarrow k^{ss}_t < k^*_{at}E/E^*$ and $k^{ss}_t > \underline{k}_t$, so $l_m = 0$ cannot be optimal; so $l_m = 1$ is optimal and $\overline{k}_t < k^{ss}_t \leq k^*_{mt}E/E^*$.

(II.2) $k^*_{at} < k^*_{mt}$. The next proof follows the same steps as in (II.1). **(II.2a)** $n \in (n^*_m, n^*_a) \Rightarrow \underline{k}_t < k^*_{at}E/E^* < k^*_{mt}E/E^* < \overline{k}_t$, so steady state equilibrium implies $l^{ss}_a > 0$ and $l^{ss}_m > 0$ with $k^*_{at}E/E^* < k^*_t < k^*_{mt}E/E^*$. **(II.2b)** $n_t \geq n^*_{at} \Rightarrow k^*_{at}E/E^* < \underline{k}_t < k^*_{mt}E/E^* < \overline{k}_t$ or $k^*_{at}E/E^* < k^*_{mt}E/E^* < \underline{k}_t < \overline{k}_t$, so $l^{ss}_m = 0$ and $k^*_{at}E/E^* \leq k^{ss}_t < \underline{k}_t$. **(II.2c)** $n_t \leq n^*_{mt} \Rightarrow \underline{k}_t < k^*_{at}E/E^* < \overline{k}_t < k^*_{mt}E/E^*$ or $\underline{k}_t < \overline{k}_t < k^*_{at} < k^*_{mt}$, so $l^{ss}_m = 1$ and $\overline{k}_t < k^{ss}_t \leq k^*_{mt}E/E^*$.

Part (b). Equation (25) implies that $r_{kt} = r^*_{kt}$ in all nations at steady state. Under steady state diversified production equilibrium, equations (11) to (13), (22) and (25) imply that, in the long-run

$$\frac{k^{ss}_{mt}}{E_{mt}} = \left[p^*_t \frac{B}{A} \left(\frac{E_{mt}}{E_{at}}\right)^{1-\alpha} \left(\frac{\theta}{\alpha}\right)^{\alpha} \left(\frac{1-\theta-\gamma}{1-\alpha-\beta}\right)^{1-\alpha-\beta} \left(\frac{\gamma}{\beta}\right)^{\beta} \left(\frac{\theta}{G_k\rho^{-1}+\delta-1}\right)^{\frac{\beta-\gamma}{\gamma}} \right]^{\frac{\gamma}{(1-\theta)\beta-(1-\alpha)\gamma}}. \tag{34}$$

Hence, because in each sector technical progress occurs at the same rate in all countries, $k^{ss}_{mt}/E_{mt} = k^*_{mt}/E^*_{mt}$. (16) and (17) $\Rightarrow$ $k^{ss}_{at}/E_{at} = k^*_{at}/E^*_{at}$ and $w^{ss}_t/E_{it} = w^*_t/E^*_{it}$, $i = a, m$. (18), (19) and (22) $\Rightarrow$ $n^{ss}_{it} = n^*_{it}$ and so $r^{ss}_{nt}/E_{it} = r^*_{nt}/E^*_{it}$, $i = a, m$. So sector-efficiency-adjusted factor price equalization holds.

Part (c) follows directly from (24), (6) and (7).

The world economy Assume that all developed countries are at steady state and share the same endowments. So the equilibrium for the developed world economy will be the same as the equilibrium for a single large and closed economy, and it will not be affected by the behavior of the small (still developing) country. Then the world market clearing conditions for final goods are

$$\begin{aligned} c_{at} &= l_{at}y_{at} = AE^{1-\alpha}_{at} l_{at} k^{\alpha}_{at} n^{\beta}_{at}, & (35)\\ c_{mt} + x_t &= l_{mt}y_{mt} = BE^{1-\theta}_{mt} l_{mt} k^{\theta}_{mt} n^{\gamma}_{mt}; & (36) \end{aligned}$$

where $y_{it} = Y_{it}/L_{it}$. In equilibrium, the world economy will produce positive amounts of both goods. An expression for x_t can be obtained using (35) and (36): $x_t = \frac{Y_{mt}}{L_t} - c_{mt} = \frac{Y_{mt}}{L_t} - \left(\frac{c_{mt}}{c_{at}}\right)\frac{Y_{at}}{L_t}$. Then using (4), $x_t = y_{mt}l_{mt} - \left(\frac{1-\varphi}{\varphi p_t}\right) y_{at}l_{at}$. Finally, using (11), we can write output as a function of the interest rate and capital, the resulting expression along with (16) and (17) imply that

$$x_t = \frac{r_{kt}}{p_t} k_{mt} \left[\left(\frac{l_{mt}}{\theta}\right) - \left(\frac{1-\varphi}{\varphi}\right) \frac{(1-\theta-\gamma)\alpha}{\theta(1-\alpha-\beta)} \left(\frac{l_{at}}{\alpha}\right) \right]. \tag{37}$$

Conditions (11), (12) and (13) imply that the price of non-primary goods is

$$p_t = \frac{AE^{1-\alpha}_{at}}{BE^{1-\theta}_{mt}} \left(\frac{\alpha}{\theta}\right)^{\alpha} \left(\frac{\beta}{\gamma}\right)^{\beta} \left(\frac{1-\alpha-\beta}{1-\theta-\gamma}\right)^{1-\alpha-\beta} k^{\alpha-\theta}_{mt} n^{\beta-\gamma}_{mt}. \tag{38}$$

Condition (25) and equations (3) and (37) imply that, at the steady state

$$k^*_t = k^*_{mt} \left(\frac{G^*_k\rho^{-1}+\delta-1}{G_L G^*_k+\delta-1}\right) \left[\frac{l^*_m}{\theta} - \left(\frac{1-\varphi}{\varphi}\right) \frac{(1-\theta-\gamma)\alpha}{\theta(1-\alpha-\beta)} \frac{l^*_a}{\alpha} \right],$$

where G^*_k is the gross growth rate of capital per capita along the balanced-growth path defined in the next section. Substituting (20) for k^*_t in the last expression, k^*_{mt}

cancels out in both sides. Then, using (8), we find that l^*_{mt}, and so $l^*_{at} = 1 - l^*_m$, does not depend on land:

$$l^*_m = \frac{\frac{(1-\theta-\gamma)\alpha}{\theta(1-\alpha-\beta)}\left[1+\left(\frac{1-\varphi}{\alpha\varphi}\right)\frac{G^*_k\rho^{-1}+\delta-1}{G_L G^*_k+\delta-1}\right]}{\frac{G^*_k\rho^{-1}+\delta-1}{\theta\left(G_L G^*_k+\delta-1\right)} - 1 + \frac{(1-\theta-\gamma)\alpha}{\theta(1-\alpha-\beta)}\left[1+\left(\frac{1-\varphi}{\alpha\varphi}\right)\frac{G^*_k\rho^{-1}+\delta-1}{G_L G^*_k+\delta-1}\right]}. \tag{39}$$

Substituting (39) into (21) we can solve for n^*_{mt} and then use (22) and (25) to get k^*_{mt}. Expressions for n^*_{at} and k^*_{at} follow from conditions (16) to (19). Substituting k^*_{mt} and l^*_m into (20) yields k^*_t, and substituting k^*_{mt} and n^*_{mt} into (38) yields p^*_t. Note that (21) and (20) then imply that the ratios k^*_t/k^*_{mt} and n^*_t/n^*_{mt} are constant and independent of n_t. So, for a proportional change dn/n, it follows from (22) and (20) that $dk/k = dk^*_m/k^*_m = [\gamma/(1-\theta)]\ dn^*_m/n^*_m = [\gamma/(1-\theta)]\ dn/n$. And from (40) that $dp^*/p^* = \frac{\beta(1-\theta)-\gamma(1-\alpha)}{1-\theta}\ dn/n$. Therefore, in the closed economy larger amounts of land have always positive effects on the stock of capital and on total output.

From (39), we can obtain the rest of the world's steady state equilibrium variables. Note that the world's capital k^*_t is always positively related to the world's relative natural endowment n^*_t, but that p^*_t can be increasing or decreasing in n^*_t depending on the relative use of the natural input across sectors. Using (38) we find that:

$$p^*_t = \frac{\frac{A}{B}\left(\frac{E^*_{at}}{E^*_{mt}}\right)^{1-\alpha}\left(\frac{\alpha}{\theta}\right)^{\alpha}\left(\frac{\beta}{\gamma}\right)^{\beta}\left(\frac{1-\alpha-\beta}{1-\theta-\gamma}\right)^{1-\alpha-\beta}\left(\frac{\theta}{G^*_k\rho^{-1}+\delta-1}\right)^{\frac{\alpha-\theta}{1-\alpha}}}{\left(\frac{(1-\theta-\gamma)\beta}{(1-\alpha-\beta)\gamma}+l^*_m\left(1-\frac{(1-\theta-\gamma)\beta}{(1-\alpha-\beta)\gamma}\right)\right)^{\frac{\beta(1-\theta)-\gamma(1-\alpha)}{1-\theta}}} {n_t^*}^{\frac{\beta(1-\theta)-\gamma(1-\alpha)}{1-\theta}}, \tag{40}$$

where l^*_m is given by (39). Regarding the convergence speed for the developed world, it can be shown that equilibrium conditions imply that the Jacobean matrix of the normalized dynamic system at the steady state does not depend on n_t, hence neither does the convergence speed of the closed economy.

Steady-state growth, normalized variables, and the equation system Growth rates along the balanced growth path in the developed world and the developing country coincide. In particular, equilibrium conditions (8) to (10) imply that $G^*_{l_a} = G^*_{l_m} = 0$, $G^*_{k_a} = G^*_{k_m} = G^*_k = G^*_x$ and that $G^*_{n_a} = G^*_{n_m} = G^*_n = G_L^{-1}$. Expression (23) says that $G^*_y = G^*_{y_a} = G^*_p G^*_{y_m}$. Budget constraint (2) and equation (3) imply, in turn, the following steady-state conditions: $G^*_c = G^*_{c_a} = G^*_p G^*_{c_m} = G^*_p G^*_x = G^*_p G^*_k = G^*_{r_n} G_L^{-1} = G^*_w$, and $G^*_{r_k} = G^*_p$. This and production functions (6) and (7) give the growth rate for output and prices as $G^*_y = G^{1-\alpha}_{E_a} G^{\alpha}_{E_m} G_L^{-[\beta+\alpha\gamma/(1-\theta)]}$ and $G^*_p = \left[(G_{E_a}/G_{E_m}) G_L^{\gamma/(1-\theta)\ -\beta/(1-\alpha)}\right]^{1-\alpha}$, respectively.

In order to obtain an equation system composed of variables that reach constant values at steady state, we carry out the following normalization suggested by the previous paragraph. We define $\hat{z} = \frac{z}{E_a}(pL^{\beta})^{1/(1-\alpha)}$, for $z = k, y_m, c_m, x, k_m, k_a$. Let us also define $\hat{v} = \frac{v}{E_a}(p^{\alpha}L^{\beta})^{1/(1-\alpha)}$, for $v = y, c_a, y_a, c, w$. Finally, $\hat{p} = p/[(E_a/E_m)L^{\gamma/(1-\theta)\ -\beta/(1-\alpha)}]^{1-\alpha}$.

The system of equations that characterizes equilibria is composed of equations (2) to (5), (11), (13), (20), (21), (24), (35), (36) and (38) for the developed world, taking G_L, G_{E_a}, G_{E_m}, N, and $E_{m_0} = E_{a_0} = E$ as given. For the developing nation that takes international product prices as given, the equation system is the same except that expressions (4), (35) and (36) are not needed, and the evolution of p is exogenously given by G_p^*.

In terms of the normalized variables, the above system for the developed world can be written as:

$$\frac{\hat{c}_{t+1}}{\hat{c}_t} = \frac{\left(G_{p_t} G_L^{\beta}\right)^{\frac{1}{1-\alpha}}}{G_{E_a}} \rho(\hat{r}_{kt+1} + 1 - \delta), \quad \text{with } \hat{r}_{kt} = \theta \; \hat{p}_t^{\frac{1-\theta}{1-\alpha}} \hat{k}_{mt}^{\theta-1} \left(\frac{N_{mt}}{l_{mt}}\right)^{\gamma}, \tag{41}$$

$$\text{and } \; G_{p_t} = \frac{\hat{p}_{t+1}}{\hat{p}_t} \left(\frac{G_{E_a} G_L^{\frac{\gamma}{1-\theta} - \frac{\beta}{1-\alpha}}}{G_{E_m}}\right)^{\frac{1}{1-\alpha}}; \tag{42}$$

$$\hat{k}_{t+1} = \left(\frac{G_{pt}}{G_L^{1-\alpha-\beta}}\right)^{\frac{1}{1-\alpha}} G_{E_a}^{-1} \left[(1-\delta)\hat{k}_t + \hat{x}_t\right]; \tag{43}$$

$$\hat{w}_t \frac{\left[1 + l_{mt}\left(\frac{\theta+\gamma-\alpha-\beta}{1-\theta-\gamma}\right)\right]}{1-\alpha-\beta} = \hat{c}_t + \hat{x}_t, \; \text{ with } \hat{w}_t = (1-\theta-\gamma) B \hat{p}_t^{\frac{1-\theta}{1-\alpha}} \hat{k}_{mt}^{\theta} \left(\frac{N_{mt}}{l_{mt}}\right)^{\gamma}; \tag{44}$$

$$\hat{k}_t = \hat{k}_{mt} \left[(1 - l_{mt}) \left(\frac{\alpha}{\theta}\right) \frac{1-\theta-\gamma}{1-\alpha-\beta} + l_{mt}\right]; \tag{45}$$

$$N \; l_{mt} = N_{mt} \left[(1 - l_{mt}) \left(\frac{\beta}{\gamma}\right) \frac{1-\theta-\gamma}{1-\alpha-\beta} + l_{mt}\right]; \tag{46}$$

$$\hat{p}_t = \left[\frac{A}{B} \left(\frac{\alpha}{\theta}\right)^{\alpha} \left(\frac{\beta}{\gamma}\right)^{\beta} \left(\frac{1-\alpha-\beta}{1-\theta-\gamma}\right)^{1-\alpha-\beta} \hat{k}_{mt}^{\alpha-\theta} \left(\frac{N_{mt}}{l_{mt}}\right)^{\beta-\gamma}\right]^{\frac{1-\alpha}{1-\theta}}; \tag{47}$$

$$\frac{(1-\theta-\gamma)(1-l_{mt})}{(1-\alpha-\beta)\left(l_{mt} - \frac{\theta \hat{x}_t}{\hat{r}_{kt}\hat{k}_{mt}}\right)} = \frac{\varphi}{1-\varphi}; \tag{48}$$

$$\text{and } \; G_L, G_{E_a}, G_{E_m}, E \; \text{ given.} \tag{49}$$

And for the developing economy as (41), (43) to (47), (49), $G_{pt} = G_{p_t^*}$, and $\hat{p}_t = \hat{p}^* \left(L_t^*/L_t\right)^{\gamma(1-\alpha)/(1-\theta)-\beta}$ taken as given. Since population grows everywhere at the same rate, without loss of generality we assume $L_t^*/L_t = 1$.

The asymptotic speed of convergence For the developing economy, for which $\hat{p}_t = \hat{p}^*$, equations (41) and (47) obtain the following Euler equation for normalized consumption under diversified production:

$$\hat{c}_{t+1} = \hat{c}_t \; G_{E_m}^{-1} G_L^{\frac{\gamma}{1-\alpha}} \rho \left[\theta B v_{t+1}^* \hat{k}_{mt+1}^{\frac{\gamma(1-\alpha)-\beta(1-\theta)}{\beta-\gamma}} + 1 - \delta\right]; \tag{50}$$

where $v_t^* = \left[\frac{B}{A}\left(\frac{\theta}{\alpha}\right)^{\alpha}\left(\frac{\gamma}{\beta}\right)^{\beta}\left(\frac{1-\theta-\gamma}{1-\alpha-\beta}\right)^{1-\alpha-\beta}(\hat{p}_t^*)^{\frac{1-\theta}{1-\alpha}}\right]^{\frac{\gamma}{\beta-\gamma}}(\hat{p}_t^*)^{\frac{1-\theta}{1-\alpha}}$; and given $\hat{p}_t^* = \hat{p}^*$, $\hat{k}_{mt+1} = \hat{k}_m(\hat{k}_{t+1}, N)$ is the implicit solution to

$$\left(\frac{v_t^*}{(\hat{p}_t^*)^{\frac{1-\theta}{1-\alpha}}}\right)^{\frac{1}{\gamma}}\hat{k}_{mt}^{\frac{\theta-\alpha}{\beta-\gamma}} = \frac{N}{\frac{\gamma(1-\alpha)-\beta(1-\theta)}{\theta(1-\beta)-\alpha(1-\gamma)}\frac{\theta}{\gamma}\left(\frac{\hat{k}_t}{\hat{k}_{mt}} - \frac{\alpha(1-\theta-\gamma)}{\theta(1-\alpha-\beta)}\right) + \frac{\beta(1-\theta-\gamma)}{\gamma(1-\alpha-\beta)}}. \tag{51}$$

Expression (51) comes from combining (45) to (47). This implicit function implies that $\hat{r}_{kt+1} = \theta B v_{t+1}^* \hat{k}_{mt+1}^{[\gamma(1-\alpha)-\beta(1-\theta)]/(\beta-\gamma)} = r_k(k_{mt+1})$ around the steady state equilibrium is decreasing in $\hat{k}_{t+1}$, and increasing (decreasing) in N if $\hat{k}_{at}^* > \hat{k}_{mt}^*$ ($\hat{k}_{at}^* < \hat{k}_{mt}^*$).

From equations (43) to (45), and (47), the law of motion for normalized capital per worker is

$$\hat{k}_{t+1} = G_{E_m}^{-1} G_L^{\frac{\gamma}{1-\theta}-1}\left[\hat{y}_t - \hat{c}_t + (1-\delta)\hat{k}_t\right], \tag{52}$$

where, under diversified production, normalized income is

$$\hat{y}_t = B v_t^* \hat{k}_{mt}^{\frac{\beta\theta-\gamma\alpha}{\beta-\gamma}}\left[\frac{1-\theta-\gamma}{1-\alpha-\beta} + \frac{\theta(\alpha+\beta-\theta-\gamma)}{\alpha(1-\gamma)-\theta(1-\beta)}\left(\frac{\hat{k}_t}{\hat{k}_{mt}} - \frac{\alpha(1-\theta-\gamma)}{\theta(1-\alpha-\beta)}\right)\right]. \tag{53}$$

As in previous literature, we next linearize the dynamic system described by expressions (50) and (52) around the steady state to get $\hat{c}_{t+1} = \Phi\left(\hat{k}_t, \hat{c}_t; N\right)$ and $\hat{k}_{t+1} = \Psi\left(\hat{k}_t, \hat{c}_t; N\right)$. The asymptotic speed of convergence of income per capita in our discrete time model is given by

$$-\frac{(G_y^*\hat{y}_{t+1} - \hat{y}_t) - (G_y^*\hat{y}^{ss} - \hat{y}^{ss})}{\hat{y}_t - \hat{y}^{ss}} = 1 - \lambda G_y^*, \tag{54}$$

where λ is the stable root of the linearized dynamic system associated to equations (50) and (52) under diversified production. This exercise also reveals that the transition is characterized by a one-dimensional stable saddle-path, which in turn implies that the adjustment path is asymptotically stable and unique.

The linearization around the steady state equilibrium implies that $\lambda = \frac{1}{2}\left(\Psi_k^* + \Phi_c^* - \Delta^{1/2}\right)$, with $\Delta = (\Psi_k^* - \Phi_c^*)^2 + 4\Psi_c^*\Phi_k^*$, where the subscripts stand for partial derivatives and the asterisk means steady state value. In a diversified production equilibrium Ψ_c^* does not depend on N, but Ψ_k^*, Φ_c^* and Φ_k^* do. In all numerical experiments: $\Delta > 0$, $2 > \Psi_k^* > \Phi_c^* > 1$, $\Psi_c^* < 0$, $\Phi_k^* < 0$; Ψ_k^*, Φ_c^* and Φ_k^* are monotone functions of N, $\Psi_{kn}^* > 0$, $sign(\Phi_{kn}^*) = -sign(\Phi_{cn}^*)$, $\Phi_{kn}^* > 0$ if $\alpha > \theta$, $\Phi_{kn}^* < 0$ if $\alpha < \theta$. If $\alpha = \theta$, $\Psi_{kn}^* = \Phi_{cn}^* = \Phi_{kn}^* = 0$. The slope of the saddle path at the steady state is $(\Psi_k^* - \lambda)/(-\Psi_c^*)$. The effect of N on λ can be written as

$$\lambda_n = \frac{1}{2}\left[\left(1 - \frac{\Psi_k^* - \Phi_c^*}{\Delta^{1/2}}\right)\Psi_{kn}^* + \left(1 + \frac{\Psi_k^* - \Phi_c^*}{\Delta^{1/2}}\right)\Phi_{cn}^*\right] - \frac{\Psi_c^*}{\Delta^{1/2}}\Phi_{kn}^*. \tag{55}$$

In all numerical examples the sign of this derivative coincides with the sign of Φ^*_{kn}, which in turn is driven by the sign of $\partial^2 \hat{r}_{kt+1}/\partial\hat{k}_t\partial N$ evaluated at the steady state:

$$\frac{\partial^2 \hat{r}_{kt+1}}{\partial \hat{k}_t \partial N} = r_k'' \frac{\partial \hat{k}_{mt+1}}{\partial N}\frac{\partial \hat{k}_{mt+1}}{\partial \hat{k}_t} + r_k' \frac{\partial^2 \hat{k}_{mt+1}}{\partial \hat{k}_t \partial N} > 0\ (<0)\ if\quad \alpha > \theta\ (\alpha > \theta), \tag{56}$$

where $r_k' < 0$ and $r_k'' > 0$ represent, respectively, the first and second derivatives of the function $r_k\left(k_{mt+1}\right)$ defined right below (51), $\frac{\partial \hat{k}_{mt+1}}{\partial \hat{k}_t} > 0$, $\frac{\partial^2 \hat{k}_{mt+1}}{\partial \hat{k}_t \partial N} < 0$ and $\frac{\partial \hat{k}_{mt+1}}{\partial N} < 0$ if $\alpha > \theta$, $\frac{\partial^2 \hat{k}_{mt+1}}{\partial \hat{k}_t \partial N} > 0$ and $\frac{\partial \hat{k}_{mt+1}}{\partial N} > 0$ if $\alpha < \theta$. The first term $r_k'' \frac{\partial \hat{k}_{mt+1}}{\partial N}\frac{\partial \hat{k}_{mt+1}}{\partial \hat{k}_t} = \partial^2 r_{kt+1}/\delta k_{mt+1}\partial N$ relates to what we have called the capital elasticity effect of land, and the second relates to the capital accumulation effect. From (54) the effect of the natural input on the speed of convergence is given by $-\lambda_n G_y^*$, so the sign of $-\frac{\partial^2 \hat{r}_{kt+1}}{\partial \hat{k}_t \partial N}$ drives the negative or positive response of the speed of convergence to an increase in the natural endowment.

B Service sector

In the model, all products are tradable. This is true, in general, for primary and manufacturing products. Services are, however, less tradable. Lipsey (2006), for example, reports that trade in services is around one forth of total world-wide trade in goods, and that for the U.S. it represents 40 percent and 20 percent of total exports and imports, respectively. Comparing these numbers to a share of services in GDP of around 65% for the world and 75% for the U.S. (UNCTAD statistics), it is clear that trade in services, although significant, occurs at a lower scale than in other sectors. This section studies how the introduction of the tertiary activity can affect our results.

Denote the service sector with a subindex s and provide technologies and variables related to this sector with interpretations and assumptions equivalent to the ones made for primary and non-primary goods. Also assume that the technologies and variables related to non-primary activities belong now to manufacturing. In addition, consider that preferences are

$$\sum_{t=0}^{\infty} \rho^t L_t \left[\varphi_a \ln c_{at} + \varphi_m \ln c_{mt} + (1-\varphi_a-\varphi_m)\ln c_{st}\right], \tag{57}$$

and the household's budget constraint is

$$c_{at} + p_{mt}(c_{mt} + x_t) + p_{st}c_{st} = r_{kt}k_t + r_{nt}n_t + w_t, \tag{58}$$

where p_{mt} and p_{st} are the price of manufacturing goods and services, respectively. Production of services is possible according to:

$$Y_{st} = E_{st}^{1-\lambda} K_{st}^{\lambda} N_{st}^{\mu} L_{st}^{1-\lambda-\mu} = E_{st}^{1-\lambda} L_{st} k_{st}^{\lambda} n_{st}^{\mu}, \quad \lambda, \mu, \lambda+\mu \in (0,1). \tag{59}$$

We assume that production in the other two sectors is given by (6) and (7), and that primary goods are still the most natural resource intensive, $\mu < \beta$.

Equilibrium conditions (8) to (10) become:

$$l_{at} + l_{mt} + l_{st} = 1, \tag{60}$$

$$l_{at}k_{at} + l_{mt}k_{mt} + l_{st}k_{st} = k_t, \tag{61}$$

$$l_{at}n_{at} + l_{mt}n_{mt} + l_{st}n_{st} = n_t. \tag{62}$$

And equilibrium in goods markets now require:

$$c_{at} + p_{mt}(c_{mt} + x_t) = l_{at}y_{at} + p_{mt}\ l_{mt}y_{mt}, \tag{63}$$

$$c_{st} = l_{st}y_{st}. \tag{64}$$

Maximizing (57) subject to (58) gives:

$$\left(\frac{\varphi_a}{c_{at}}\right)p_{mt} = \frac{\varphi_m}{c_{mt}} = \left(\frac{1-\varphi_a-\varphi_m}{c_{st}}\right)\frac{p_{mt}}{p_{st}}, \tag{65}$$

and

$$\frac{c_{t+1}}{c_t} = \frac{p_{m,t+1}}{p_{mt}}\rho\left(\frac{r_{kt+1}}{p_{m,t+1}} + 1 - \delta\right), \tag{66}$$

where $c_t = c_{at} + p_{mt}c_{mt} + p_{st}c_{st}$.

Profit maximization by firms, in turn, gives:

$$\begin{aligned} r_{kt} &= \alpha E_{at}^{1-\alpha}k_{at}^{\alpha-1}n_{at}^{\beta} = p_{mt}\theta E_{mt}^{1-\theta}k_{mt}^{\theta-1}n_{mt}^{\gamma} = p_{st}\lambda E_{st}^{1-\lambda}k_{st}^{\lambda-1}n_{st}^{\mu},, & (67)\\ r_{nt} &= \beta E_{at}^{1-\alpha}k_{at}^{\alpha}n_{at}^{\beta-1} = p_{mt}\gamma E_{mt}^{1-\theta}k_{mt}^{\theta}n_{mt}^{\gamma-1} = p_{st}\mu E_{st}^{1-\lambda}k_{st}^{\lambda-1}n_{st}^{\mu}, & (68)\\ w_t &= (1\text{-}\alpha\text{-}\beta)\,E_{at}^{1-\alpha}k_{at}^{\alpha}n_{at}^{\beta} = p_{mt}\,(1\text{-}\theta\text{-}\gamma)\,E_{mt}^{1-\theta}k_{mt}^{\theta}n_{mt}^{\gamma} = p_{st}\,(1\text{-}\lambda\text{-}\mu)\,E_{st}^{1-\lambda}k_{st}^{\lambda}n_{st}^{\mu} & (69)\end{aligned}$$

Combining equations (58) to (62), and (65) to (69) following the same logic as for the two sector model, we obtain

$$\frac{w_t}{1-\alpha-\beta}\left[1 + l_{mt}\left(\frac{\theta+\gamma-\alpha-\beta}{1-\theta-\gamma}\right) + l_{st}\left(\frac{\lambda+\mu-\alpha-\beta}{1-\lambda-\mu}\right)\right] = c_t + p_{mt}x_t, \tag{70}$$

$$k_t = k_{mt}\left[(1-l_{mt}-l_{st})\frac{\alpha(1-\theta-\gamma)}{\theta(1-\alpha-\beta)} + l_{mt} + l_{st}\frac{\lambda(1-\theta-\gamma)}{\theta(1-\lambda-\mu)}\right], \tag{71}$$

$$n_t = n_{mt}\left[(1-l_{mt}-l_{st})\frac{\beta(1-\theta-\gamma)}{\gamma(1-\alpha-\beta)} + l_{mt} + l_{st}\frac{\mu(1-\theta-\gamma)}{\gamma(1-\lambda-\mu)}\right], \tag{72}$$

$$p_{mt} = \frac{A}{B}\frac{E_{at}^{1-\alpha}}{E_{mt}^{1-\theta}}\left(\frac{\alpha}{\theta}\right)^{\alpha}\left(\frac{\beta}{\gamma}\right)^{\beta}\left(\frac{1-\alpha-\beta}{1-\theta-\gamma}\right)^{1-\alpha-\beta}k_{mt}^{\alpha-\theta}n_{mt}^{\beta-\gamma}, \tag{73}$$

and

$$p_{st} = A\frac{E_{at}^{1-\alpha}}{E_{st}^{1-\lambda}}\left(\frac{\alpha}{\lambda}\right)^{\alpha}\left(\frac{\beta}{\mu}\right)^{\beta}\left(\frac{1-\alpha-\beta}{1-\lambda-\mu}\right)^{1-\alpha-\beta}k_{st}^{\alpha-\theta}n_{st}^{\beta-\gamma}. \tag{74}$$

Equations (3), (66), (67), and (69) to (74) form the system that characterizes the equilibrium in the developing economy with services. For this economy, the evolution of p_{mt} is exogenous and given by the developed world. It is easy to show that steady-state growth rates for all variables remain the same as in the two-sector model, except for the ones that have no mirror in that model; that is, y_{st}^*, p_{st}^* and c_{st}^*.. For these ones: $G_{y_s}^* = G_{c_s}^* = G_y^* G_{p_s}^*$, with $G_{p_s}^* = G_{E_a}^{1-\alpha} G_{E_s}^{\lambda-1} G_{E_m}^{\alpha-\lambda} G_L^{\mu-\beta+\gamma(\lambda-\alpha)/(1-\theta)}$.

Let us concentrate now on the diversified production case, whose results the introduction of services could most likely affect. Following the same steps as in section 3, we obtain that income per capita that equals $y_t = l_{at} y_{at} + p_{mt} l_{mt} y_{mt} + p_{st} l_{st} y_{st}$ now reduces to

$$y_t = \frac{w_t}{1-\alpha-\beta}\left[1 + l_{mt}\left(\frac{\theta+\gamma-\alpha-\beta}{1-\theta-\gamma}\right) + l_{st}\left(\frac{\lambda+\mu-\alpha-\beta}{1-\lambda-\mu}\right)\right]. \qquad (75)$$

This expression delivers the same result as expression (24). In particular, equation (75) says that natural riches raises output if the primary sector is less labor intensive than the other two sectors, and *vice versa*.

Comparing across economies, this remains true at steady state because long-run (efficiency-adjusted) FPE holds as well with services. To see this, notice that the Euler equation for consumption (5), and conditions (11), (22) and (38) still hold but with p_t being now relabeled p_{mt}. The system formed by these equalities imply that r_{kt}^{ss}/p_{mt}^{ss}, n_{mt}^{ss}, k_{mt}^{ss}, and w_t^{ss} are the same as their developed-world's counterparts. Hence, under production diversification, a large natural endowment decreases l_{mt}^{ss} and l_{st}^{ss} whereas w_t^{ss}/E_t remains equal to w_t^*/E_t^*, thus raising (decreasing) y_t^{ss} if primary goods are the less (most) labor intensive sector.

The impact of having services on our quantitative results is small if the elasticities in the manufacturing and service sectors are similar. To see this, let us go to the extreme and impose $\lambda = \theta$ and $\mu = \gamma$, equations (67) to (69) imply that $k_{st} = k_{mt}$, and $n_{st} = n_{mt}$. Expressions (73) and (74), in turn, say that the relationship between output prices become exogenous; in particular, $p_{mt}/p_{st} = (E_{st}/BE_{mt})^{1-\theta}$.. As a consequence, variables and parameters related to the service sector do not show up in the equation system that governs the model dynamics. The system for a developing economy is now identical to the one of the two-sector model, with the following two exceptions:

$$k_t = k_{mt}\left[l_{at}\frac{\alpha(1-\theta-\gamma)}{\theta(1-\alpha-\beta)} + l_{mt}\right], \qquad (76)$$

and

$$n_t = n_{mt}\left[l_{at}\frac{\beta(1-\theta-\gamma)}{\gamma(1-\alpha-\beta)} + l_{mt}\right]. \qquad (77)$$

Comparing (76) and (77) to (20) and (21), the difference is that instead of having $1 - l_{mt}$, we now have l_{at}.

Therefore, when input elasticities in the secondary sector are the same as in the tertiary activity, the price of services in the small open economy moves exogenously with the one of manufactures, services no longer play any role in the diversified-production equilibrium, and the model's equation system becomes almost exactly the same as the one in the two-sector model. As a consequence, predictions on the asymptotic convergence speed should as well remain similar.

Focusing on the case of land, for example, the evidence says that the above assumption is not far from reality. Herrendorf and Valentinyi (2008, table 2) report a share of equipment plus structures of 0.30, 0.28 and 0.36 for manufacturing, services and agriculture, respectively; and a land share of 0.03, 0.06 and 0.18 for the same sectors. Agriculture is clearly more capital intensive and less labor intensive than the rest of the economy.

The conclusion from this section is that the introduction of services into the framework does not change the qualitative results. In addition, taking into account that inputs shares in services and manufacturing are similar, relatively far from the ones in primary activities, and that trade in services is significant, although at about half the scale than in manufacturing and agriculture, the introduction of the tertiary sector should not either have a big impact on our quantitative findings.

C Two-country world: small *versus* open

In this appendix, we explore the relationship between the natural input and long-run income in a two-country diversified production equilibrium. Market clearing conditions (35) and (36) become

$$
\begin{aligned}
s^1 c^1_{at} + (1-s^1) c^2_{at} &= s^1 l^1_{at} y^1_{at} + (1-s^1) l^2_{at} y^2_{at}, &(78)\\
s^1 \left(c^1_{mt} + x^1_t\right) + (1-s^1)\left(c^2_{mt} + x^2_t\right) &= s^1 l^1_{mt} y^1_{mt} + (1-s^1) l^2_{mt} y^2_{mt}, &(79)
\end{aligned}
$$

where the superscript stands for country $h = 1, 2$, and s^1 is the population of country 1 relative to the world population. Proceeding as in the previous case of the world economy in this appendix, we obtain an equilibrium condition that now depends on l^A_{mt} and l^B_{mt}. Note that all the optimality conditions obtained for the small open economy in a diversified production equilibrium apply to countries 1 and 2 in this two-country world. For simplicity, suppose that population growth is zero and that sectorial productivities are constant. The optimality conditions and the Euler equations for each country imply that at the steady state: $n^h_a = n^*_a$, $n^h_m = n^*_m$, $k^h_m/E^h = k^*_m = (\frac{\rho^{-1}+\delta-1}{\theta})^{1/(\theta-1)} n^{*\gamma/(1-\theta)}_m$ and $l^h_m = \frac{\beta(1-\theta-\gamma)}{\beta(1-\theta-\gamma)-\gamma(1-\alpha-\beta)}\left(1-\frac{n^h}{n^*_a}\right)$ for all h. Then the market clearing conditions imply that the steady state solution for n^*_a is

$$
n^*_a = \frac{s^1 n^1 + \left(1-s^1\right) n^2 E^2/E^1}{s^1 + (1-s^1) E^2/E^1 + \left(\frac{\gamma(1-\alpha-\beta)}{\beta(1-\theta-\gamma)} - 1\right)\left(\frac{T_2}{T_1+T_2-1}\right)} \tag{80}
$$

where n^h is the N-labor endowment of country h, and $T_1 = \frac{\rho^{-1}+\delta-1}{\theta(1+\delta-1)}$ and $T_2 = \left(\frac{1-\theta-\gamma}{1-\alpha-\beta}\right)\left(\frac{\alpha}{\theta} + T_1(1-\varphi)/\varphi\right)$ are positive constants. Use this solution to compute

k_m^* and n_m^* and substitute the resulting expressions into (38) to obtain the steady state price of manufactures, $p(n_a^*)$, which is positively related to n^1 and n^2. In this scenario the long-run per capita values of capital and income in country h are

$$\begin{aligned} k^h &= E^h k_m^* \left[\frac{\alpha(1-\theta-\gamma)}{\theta(1-\alpha-\beta)} + \left(1 - \frac{\alpha(1-\theta-\gamma)}{(1-\alpha-\beta)\theta}\right) l_m^h \right], \\ y^h &= \frac{E^h k_m^*}{\theta} (\rho+\delta-1)\, p(n_a^*) \left[\frac{1-\theta-\gamma}{1-\alpha-\beta} + \left(1 - \frac{(1-\theta-\gamma)}{1-\alpha-\beta}\right) l_m^h \right]. \end{aligned}$$

It follows from the first expression and the optimal values of k_m^* and l_m^h that, if primary goods are more capital intensive, an increase in the natural endowment of country h will have a positive effect on its steady state capital but an ambiguous effect on the capital stock of the other country. And viceversa if manufacture goods are more capital intensive (the ambiguous effect will be on the capital stock of country h and the positive effect will go to the capital stock of the other country). Part of this ambiguity comes from the positive effect of n^h on n_a^*, which depends on the relative size of population in country h. Similarly, it follows from the income expression that the effect of an increase in n^h on y^h is positive if the primary sector is more labor intensive than the non-primary activity, otherwise the effect is ambiguous. In this case the ambiguity also comes from the positive effect of n^h on $p(n_a^*)$. Assuming, for example, that both countries have the same population size and the same N-labor endowment, a marginal increase in the natural endowment of country 1 always has a positive effect on its long-run income, regardless of capital or labor shares. Moreover, in the limit case when the relative size of country 1 is one (country 1 is large and open, country 2 becomes a small open economy), the total effect of n^1 on l_m^1 is zero, as we showed in (39), and the effect on both long-run capital and income is positive.

References

Acosta, A., *La maldición de la abundancia*, Ediciones Abya-Yala, Quito, Ecuador, 2009. Downloadable at http://www.extractivismo.com/documentos/AcostaMmaldicionAbundancia09

Adamopoulos, T., "Land Inequality and the Transition to Modern Growth," *Review of Economic Dynamics* 11(2), 2008.

Alexeev, M., and R. Conrad, "The Elusive Curse of Oil," *Review of Economics and Statistics* 91(3): 586-98, 2009.

Atkeson, A., and P. Kehoe, "Paths of development for early- and late-bloomers in a Dynamic Heckscher-Ohlin Model," *Federal Reserve Bank of Minneapolis working paper*, 2000.

Ashraf, Q., and O. Galor, "Malthusian Population Dynamics: Theory and Evidence," Brown University, *Mimeo*, March 2008.

Bajona, C., and T.J. Kehoe, "Demographics in a Dynamic Heckscher-Ohlin Model," *NBER Working Paper* 12566, 2006.

Bajona, C., and T.J. Kehoe, "Trade, Growth and Convergence in a Dynamic Heckscher-Ohlin Model," *Review of Economic Dynamics* 13: 487–513, 2010.

BP, *Statistical Review of World Energy 2010*, B.P. p.l.c., London, June 2010.

Caselli, F., "Power Struggles and the Natural Resource Curse," *mimeo*, London School of Economics, 2006.

Caselli, F., and W.J. Coleman, "The U.S. Structural Transformation and Regional Convergence: A Reinterpretation" *Journal of Political Economy* 109(3):584-616, June 2001.

Doppelhofer, D., R. Miller and X. Sala-i-Martin, "Determinants of Long-Term Growth: A Bayesian Averaging of Classical Estimates (BACE) Approach," *American Economic Review*, September 2004.

Eaton, J., "Foreign public capital flows," in: Chenery and Srinivarsan (Eds.), *Handbook of Development Economics*, Vol. II, North-Holland, Amsterdam, pp. 1305–1386, 1992.

Echevarria, C., "Nonhomothetic Preferences and Growth," *Journal of International Trade and Economic Development*, 9(2):151-172, June 2000.

Edwards, S., Van Wijbergen, S., "Disequilibrium and structural adjustment," in: Chenery and Srinivarsan (Eds.), *Handbook of Development Economics*, Vol. II, North Holland, Amsterdam, pp. 1481–1533, 1992.

Economic Report of the President, United States government printing office, washington, 2004.

Frankel, J.A., "The Natural Resource Curse: A Survey," *NBER W.P.* No. 15836, March 2010.

Gallup, J.L., J.D. Sachs and A.D. Mellinger, "Geography and Economic Development," in Pleskovic, B., and J.E. Stiglitz, eds., *World Bank Annual Conference on Development Economics 1998*, Washington: World Bank, 1999.

Galor, O., O. Moav and D. Vollrath, “Land Inequality and the Emergence of Human Capital Promoting Institutions,” *Review of Economic Studies* 75, 2008.

Galor, O., and A. Mountford, “Trade and the Great Divergence: The Family Connection,” *American Economic Review* 96, pp. 229-303, May 2006.

Galor, O., and A. Mountford, “Trading Population for Productivity: Theory and Evidence”, *Review of Economic Studies* 75(4): 1143-1179, October 2008.

Galor, O., and D. Weil, “From Malthusian Stagnation to Modern Growth,” *American Economic Review* 89, 150-154, May 1999.

Galor, O., and D. Weil, “Population, Technology, and Growth: From Malthusian Stagnation to the Demographic Transition and beyond,” *American Economic Review* 90(4): 806-828, September 2000.

Gollin, D., S.L. Parente and R. Rogerson, “The Food Problem and the Evolution of International Income Differences,” *Journal of Monetary Economics* 54(4), pp. 1230-1255, 2007.

Guilló, M.D., and F. Perez-Sebastian, “Paths of Development in Open Economies: The Role of Land,” *IVIE working paper WP-AD 2005-31*, 2005.

Guilló, M.D., and F. Perez-Sebastian, “The Curse and Blessing of Fixed Specific Factors in Small-Open Economies,” *Journal of Development Economics*, Vol. 82, 58-78, 2007.

Guilló, M.D., and F. Perez-Sebastian, “Paths of Development for Early- and Late-Bloomers with Land” *mimeo*, University of Alicante, 2008.

Gylfason, T., “Natural Resources, Education, and Economic Development,” *European Economic Review* 45: 847-859, 2001

Hansen, G.D., and E.C. Prescott, “Malthus to Solow,” *American Economic Review*, 1205-1217, September 2002.

Hayami, Y., and V. Ruttan, *Agricultural Development: An International Perspective, Revised and Extended Edition*, John Hopkins University Press, 1985.

Hodler, R., “The Curse of Natural Resources in Fractionalized Countries,” *European Economic Review* 50, no. 6, 1367-86, 2006.

Herrendorf, B., and A. Valentinyi, “Measuring Factor Income Shares at the Sectoral Level,” *Review of Economics Dynamcis* 11, 820-835, 2008.

Irz, X., and T. Roe, “Seeds of Growth? Agricultural Productivity and the Transitional Dynamics of the Ramsey Model,” *European Review of Agricultural Economics* 32(2): 143-165, 2005.

Isham, J., M. Woolcock, L. Pritchett, and G. Busby, “The Varieties of Resource Experience: Natural Resource Export Structures and the Political Economy of Economic Growth,” *World Bank Economic Review* 19(2): 141-174, 2005.

Jorgenson, D.W., and K.J. Stiroh, “Raising the Speed Limit: U.S. Economic Growth in the Information Age,” *Brookings Papers on Economic Activity 1*, 125-211, 2000.

Kögel, T., and A. Prskawetz, “Agricultural Productivity Growth and Escape from the Malthusian Trap,” *Journal of Economic Growth* 6:337-357, 2001.

Kongsamut, P., S. Rebelo and D. Xie., "Beyong Balanced Growth," *Review of Economic Studies* 68: 869-882, 2001.

Lipsey, R.E., "Measuring International Trade in Services," *NBER Working Paper* 12271, May 2006.

Malthus, T.R., *An Essay on the Principle of Population*. J. Johnson, in St. Paul's Church-Yard, London, UK, 1798.

Matsuyama, K., "Agricultural Productivity, Comparative Advantage, and Economic Growth," *Journal of Economic Theory* 58: 317-334, December 1992.

Mehlum, H., K. Moene and R. Torvik, "Institutions and the Resource Curse," *Economic Journal* 116: 1-20, January 2006.

Mountford, A., "Trade, convergence and overtaking," *Journal of International Economics* 46: 167-182, 1998.

Mundlak, Y., D.F. Larson and R. Butzer, "Rethinking Within and Between Regressions: The Case of Agricultural Production Functions," *Annales d'Economie et de Statistique* 55-56: 475-501, 1999.

Mundlak, Y., D.F. Larson and R. Butzer, "A Cross-Country Database for Sector Investment and Capital," *The World Bank Economic Review* 14:371-91, 2000.

Ngai, L.R. and C.A. Pissarides, "Structural Change in a Multi-Sector Model of Growth," *American Economic Review* 97: 429-443, 2007.

Papyrakis, E., and R. Gerlagh, "Resource Abundance and Economic Growth in the United States," *European Economic Review* 51, 1011–1039, 2007.

Parente, S.L., and E.C. Prescott, *Barriers to Riches*, MIT Press, 2000.

Restuccia, D., D.T. Yang and X. Zhu, "Agriculture and Aggregate Productivity: A Quantitative Cross-Country Analysis," *Journal of Monetary Economics* 55(2): 234-250, March 2008.

Sachs, J., and A. Warner, "The big push, natural resource booms and growth," *Journal of Development Economics* 59: 43–76, 1999.

Sachs, J.D. and A.M. Warner, "The curse of natural resources," *European Economic Review* 45: 827-838, May 2001.

Schultz, T.W.,"On the Economic Importance of Land: Reply," *Journal of Farm Economics* 49(3): 735-737, August 1967.

Smith, A., *An Inquiry into the Nature and Causes of the Wealth of Nations*. Ed. by E. Cannan, 1904, Methuen & Co., Ltd, London, UK, 1776.

Strulik, H., and J. Weisdorf, "Population, Food, and Knowledge: A Simple Unified Growth Theory," *Journal of Economic Growth* 13(3): 195-216, 2008.

USDA, *Agricultural Income and Finance Situation and Outlook*, United States Department of Agriculture, Economic Research Service, September 2000.

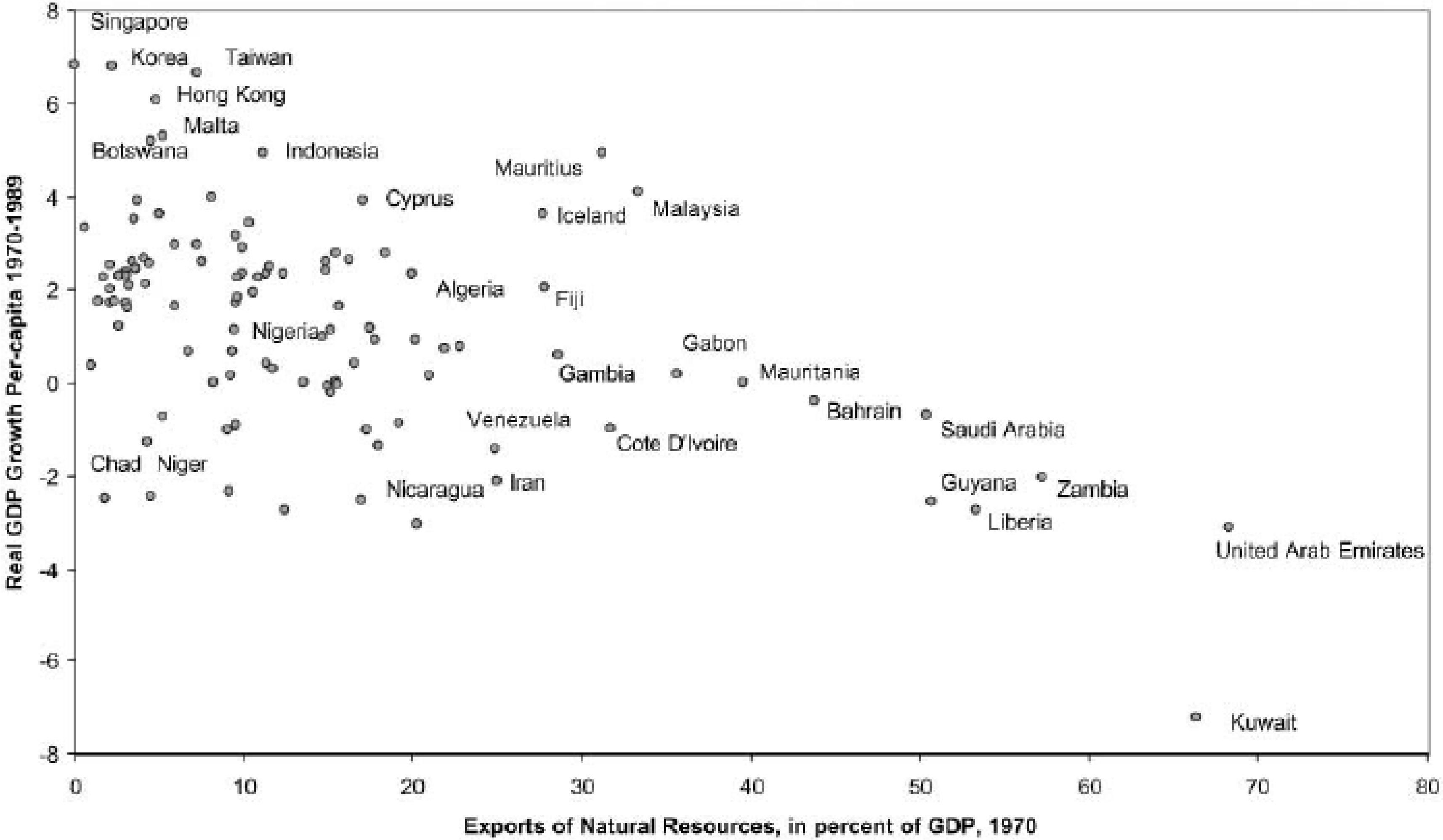
USDA, *Agricultural Land Values and Cash Rents: Final Estimates 1999-2003*, United States Department of Agriculture, National Agricultural Statistics Service, Statistical Bulletin No. 993, March 2004.

USDA, *Major Uses of Land in The United States, 2002*, United States Department of Agriculture, Economic Research Service, Economic Bulletin No. 14, May 2006.

van der Ploeg, F., "Natural Resources: Curse or Blessing?" *Journal of Economic Literature* 49, 366-420, 2011.

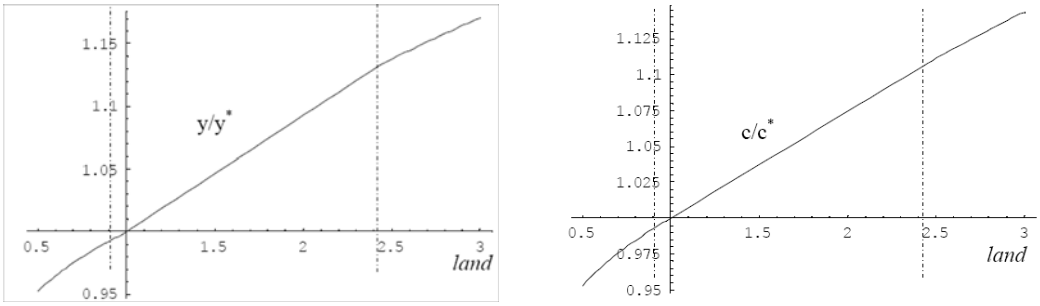
Ventura, J., "Growth and Interdependence," *Quarterly Journal of Economics*, 57-84, February 1997.

Figure 1: Growth and natural resource abundance 1970-1989

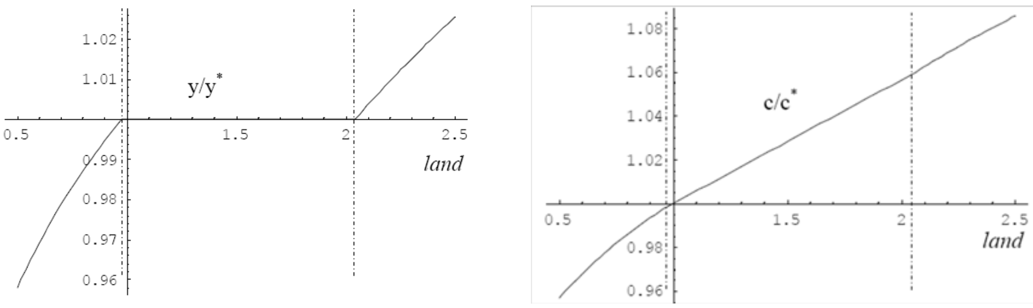


Source: Sachs and Warner (2001)

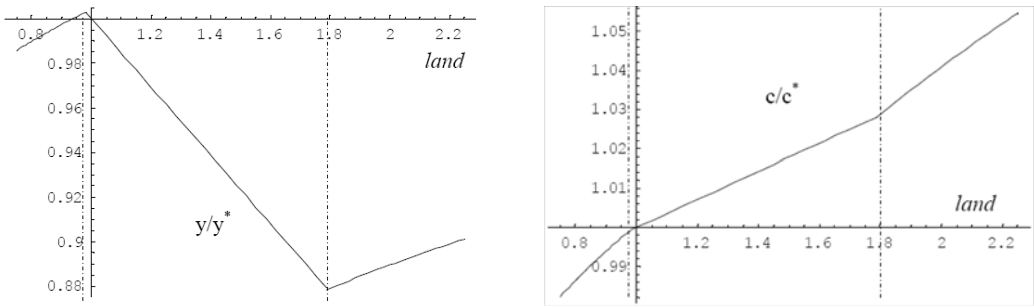
Figure 2: Long-run income (LHS panels) and consumption (RHS panels) relative to the developed world average as a function of land



$\alpha = 0.3,\ \theta = 0.28,\ \beta = 0.11,\ \gamma = 0.048$



$\alpha = 0.25,\ \theta = 0.251,\ \beta = 0.11,\ \gamma = 0.048$



$\alpha = 0.1,\ \theta = 0.253,\ \beta = 0.11,\ \gamma = 0.048$

PUBLISHED ISSUES

WP1214 'Neoclassical Growth and the Natural Resource Curse Puzzle.'
María Dolores Guilló, Fidel Pérez-Sebastián.