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Cost-Reducing R&D in the Presence of an Appropriation Alternative: An Application to the Natural Resource Curse

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Abstract

This study proposes a new mechanism for the resource curse: crowding-out of innovation due to the existence of an option to engage in conflict. Using a game theoretical framework, it is argued that an increase in the amount of natural resources (in the informal sector where conflict for a common-pool rent materializes) reduces the incentives of entrepreneurial groups to engage in cost-reducing R&D (in the non-resource sector where production occurs). Compared to most models of the resource curse, the impact of resource abundance on income and welfare was interestingly observed to be non-monotonic. An increase in the amount of resources in the common pool induces intensified conflict among groups and less R&D investment. Depending on the relative strengths of the income and diversion effects, three scenarios were exhibited. First, there is a 1.) Pure Blessing. This happens when both the extent of technological spillovers and the initial level of resource are low. Starting from scarcity, the increase in natural resource generates an overall jump in the groups' income levels. Even if an increase in resources decreases innovation in the formal sector, both income and welfare still go up. Meanwhile, for intermediate initial values of the natural resource, there is a 2.) Pseudo-curse. A resource boom induces an immediate income effect. However, this income gain is dominated by the indirect diversion effect due to lower output and higher price (because of less cost-reducing R&D). Consequently, while income increases, the welfare of the economy decreases. The range of resource levels where this occurs is greater when spillovers are high. Finally, a 3.) Double Curse occurs for extremely high initial levels of natural resources. Both aggregate income of the economy and welfare suffer.

Keywords: innovation, appropriation, natural resources
JEL Classification: O13, Q33, P48

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1 Introduction

Empirical studies suggest that countries well-endowed with natural resources tend to experience slower economic development than their resource-poor counterparts (Sachs and Warner, 1995; 1997; 2001)[1]. This puzzle, the so-called "natural resource curse", has resulted to different explanations.[2] The first stream of research pertains to the Dutch disease and deindustrialization. It notes that resource abundance shifts factors of production out of sectors characterized by increasing returns to scale (Krugman, 1987; Matsuyama, 1992; and Gylfason et al., 1999). Another explanation emphasizes the role of institutions. The transmission channels for this stream can be distinguished into two: 1. centralized and 2. decentralized mechanisms. The centralized mechanism hypothesizes that when ruling elites are not benevolent, they tend to use resource income for personal gain instead of public good provision (Caselli and Cunningham, 2009). Meanwhile, the decentralized mechanism focuses on rent-seeking and conflict among societal groups (Torvik (2002), Wick and Bulte (2006), Lane and Tornell (1996), and Tornell and Lane (1999)). Nonetheless, Mehlum et al. (2006) observed that when institutions are strong, more natural resources may eventually push aggregate income up.

These propositions on why there is a resource curse usually follow a crowding-out logic. An abundance or dependence on natural resources crowds out a growth-enhancing activity. This present study addresses an additional channel through which natural resource wealth may affect income and social welfare. It argues that an increase in the amount of natural resources reduces the incentives of entrepreneurial groups to engage in cost-reducing R&D in the non-resource sector. Further motivation is provided by the observation that resource-rich countries tend to innovate less.[3]For instance, Maloney (2002)'s

[1]However, there exists two new empirical findings on the resource curse. Compared to Sach and Warner's utilization of export dependence datasets, Brunnschweiler and Bulte (2008) employed new natural capital data from the World Bank. They found out that resource abundance does not induce any "curse". On the other hand, van der Ploeg and Poelhekke (2010) argued that the resource curse is not an entirely flawed concept. They noted that natural resource price volatilities may slow down growth rates.

[2] Besides the popular channels mentioned below, other hypotheses have recently emerged. These include fractionalization and excessive investment (van der Ploeg, 2010), and negative savings rates in resource-rich, developing countries (van der Ploeg, 2010).

[3]Indeed, innovation has been well-regarded as an engine for economic development. For

historical anecdote observed that Latin American countries missed opportunities for natural resource-based growth. He argued that these countries lack the innovative capacity arising from low investments in scientific infrastructure and human capital. Empirically, using state-level US data, Papyrakis and Gerlagh (2007) has also shown that resource abundance decreases R&D (Research and Development) expenditure.

The contributions of this study are three-fold. First, it focuses on an interesting game theoretic, innovation-based approach on the natural resource curse. While Peretto and Valente (2011) and Peretto (2012) have recently analyzed the role of natural resources on R&D, they only do so by building upon endogenous growth models. Peretto (2012) defined resource abundance as the endowment of natural resource relative to labor. The primary sector uses labor to process the resource input. The secondary sector utilizes the processed natural resource and labor as inputs. The curse may exist if the aforementioned endowment ratio is high. Finally, Peretto and Valente (2011) provided a variation by introducing international trade to the latter model. When these labor and processed resource inputs are complementary, the resource-rich economy may experience stagnant growth. Overall, while the aforementioned studies observed that the existence of more natural resource inputs reduces innovation, they are unable to address the possible strategic interactions among non-cooperative economic agents. Unfortunately, to the author's knowledge, no article on the resource curse has explored this intriguing perspective yet. In an attempt to do so, this paper presents the first game theoretic investigation of the potential trade-off between cost-reducing process innovation and resource rent appropriation. The game constitutes two stages. Compared to resource curse literature, production only takes place during the second stage. The first stage comprises of a trade-off between innovation and resource grabbing.

Second, compared again to the innovation-based models which only regarded natural resources as an input, this study's originality comes from its consideration of resource wealth as an appropriable common pool in an informal sector. This is done by utilizing the elements of a Tullock-based contest (Garfinkel and Skaperdas, 2007). Again, the informal sector co-exists with an formal sector engaged in production, e.g. manufacturing. This formal sector is then characterized by an oligopolistic relationship among groups. Acting like entrepreneurial firms, they also engage in Cournot competition. This feature of the formal sec-

more detailed examples, please refer to Aghion and Howitt (2005).

tor, e.g. manufacturing, is somehow consistent with the formalization found in d'Aspremont and Jacquemin (1988). Although the non-cooperative interaction among agents is the focus, the possibility of R&D cooperation is also considered. That is, groups may share basic information and efforts in the first stage. Nonetheless, it is assumed they remain rivals in the marketplace. As discussed in d'Aspremont and Jacquemin (1988), a realistic example is the European Strategic Program for R&D in Information Technologies. Overall, market competition is non-existent in recent static, decentralized models of the resource curse which never considered any form of market structure. Therefore, this research also provides a relatively new, yet simple insight into the relational dynamics of natural resource abundance and quantity competition. Finally, this paper incorporates the existence of technological spillovers in production. The past papers did not vary the extent of technical externalities in their models. In this regard, it is important to notice that this current study examines the possibility that cost reductions are characterized by spillovers which may vary in magnitude.

This article has shown that the impact of natural resource abundance on income and welfare is non-monotonic. [4]The general findings of this study are dependent on the different natural resource threshold levels:

1. There is a pure blessing. This only happens when both the extent of technological spillovers and the initial level of resource are low. Starting from scarcity, the increase in natural resource abundance generates a jump in the groups' income levels. Both income and welfare go up.

2. There is a pseudo-blessing. This can be observed for intermediate initial values of the natural resource. A resource boom induces an immediate increase in income. Unfortunately, the increase in aggregate income is not sufficient to outweigh the losses in consumer surplus due to lower output (and higher price). Thus, the welfare of the economy still decreases. The range of values where a pseudo-blessing occurs is greater when spillovers are high.

3. There is a double curse. This occurs for extremely high initial levels of resources. For this scenario, income and welfare both decline with a further increase in the amount of natural resource. With certainty, the decrease in income directly induces a fall in welfare. When there is a a sudden increase in wealth from natural resources, there is an intensified shifting of allocation from an innovative activity with collective benefits towards unproductive contesting.

[4]Note that there is a limited number of static models considering the impact of higher rents on welfare. The most prominent one is that of Torvik (2002).

This negative diversion effect greatly dominates the potential income gains. Therefore, the aggregate income of the economy inevitably falls. This impact is strong enough that social welfare also suffers.

This article is organized as follows. Section 2 develops the basic setup of the game. Meanwhile, Sections 3 and 4 discuss the potential solutions to the model. Section 5 then focuses on the comparative statics. Finally, Section 6 concludes.

2 The setup

Extending the static setup in Wick and Bulte (2006), consider an economy that consists of two risk-neutral groups. These groups can be regarded as conflicting tribes (Hodler, 2006) or more aptly, entrepreneurial firms (Torvik, 2002). It is noteworthy to emphasize, however, that this model differs because it is a two-stage game where the nature of interaction differs between the two periods. In the first stage, each group i has an exogenous, total amount of endowment E_i to be allocated between cost-reducing R&D efforts in the productive sector (e.g. manufacturing) x_i and resource rent appropriation f_i. In the second stage, given their prior investment decisions, the groups simultaneously set output in the productive sector. Notice that a greater market share in the second stage, i.e. capability to produce more output, provides incentives for groups to invest in cost-reducing R&D in the first stage.

The productive, formal sector is assumed to be duopolistic in nature. It is characterized by an inverse demand function $P(Q)$, where $Q = q_i + q_j = q_1 + q_2$ is the total quantity produced.[5] Each group's unit cost is denoted as $c_i(x_i, x_j)$ which is a function of the amount of R&D effort it invests x_i and the amount of research x_j that the other group undertakes. Assuming linearity, $P(Q)$ and $c_i(x_i, x_j)$ are denoted as follows: $P(Q) = d - bQ$ and $c_i(x_i, x_j) = (A - x_i - \beta x_j)\ \forall i, j \neq i$. To guarantee a solution, it is also assumed that $0 < A < d$ and $\beta \epsilon (0, 1)$.

In contrast to existing resource curse literature, technological spillovers are presumed to exist as in d'Aspremont and Jacquemin's (1988). In this case,

[5]Resource curse literature (refer to van der Ploeg (2011) for a comprehensive survey) usually assume that the payoffs from the productive sector is merely equal to the allocation to production multiplied by a parameter, e.g. $Y_i = AL_i$. The profit is equivalent to the output itself. Deviating from these, this paper assumes that the productive sector is characterized by an economic market where groups engage in quantity competition.

group j 's R&D effort lowers firm i's unit production cost by a factor β. While d'Aspremont and Jacquemin (1988) consider an explicit cost of R&D investment, this article follows the usual specification in resource curse (Wick and Bulte, 2006) and conflict literature (Garfinkel and Skaperdas, 2007). As noted previously, groups have a fixed endowment in private resources. This implies that investing in R&D reduces the amount of endowment available for the competing activity.

Assuming homogeneity in output q in the second stage, the group's payoff from the productive sector M is denoted as:

$$\Pi_{iM} = [P(Q) - c_i(x_i, x_j)]\, q_i \tag{1}$$

Alternatively, in the first stage, groups can invest in an informal sector F. With the prevalence of weak property rights in the economy, activity in the informal sector pertains to contesting for a common pool. More specifically, groups have the opportunity to capture natural resource rents. Torvik (2002) discussed that these rents can also be considered as public sector income subject to a political struggle among entrepreneurial firms.

Group i's expected payoff from appropriation is given by:

$$\Pi_{iF} = h_i(f_i, f_j)\, R \tag{2}$$

where R is the total value of the natural resource rent in the common pool and $h_i(f_i, f_j)$ is the contest success function. It is assumed that the contest success function takes the most commonly used functional form (see Garfinkel and Skaperdas, 2007).[6]

$$h_i(f_i, f_j) = \begin{cases} \frac{fi}{fi+fj} & if\, f_i + f_j > 0; \\ \frac{1}{2} & otherwise \end{cases} \tag{3}$$

$h_i(f_i, f_j)$ determines the share of the natural resource rent that i will obtain, given it invests f_i to appropriation and j allocates f_j. In this case, $h_1 = \frac{f_1}{f_1 + f_2}$ and $h_2 = 1 - h_1$. Intuitively, the more a group invests in appropriation (in relative terms), the higher its share of the common pool.

[6] For more details on the class of conflict technologies, refer to Tullock (1980), Hirshleifer (1989), and Konrad (2005).

3 Solution to the Model

This section solves the game using backward induction. As stated previously, in the first stage, cost-reducing R&D and resource rent appropriation investments are made. Stage 2 is characterized by a simple Cournot game.

3.1 The second stage

Conditional on the allocation decisions made in Stage 1, group i chooses the level of output that maximizes its aggegate payoffs from production and contesting. Adding up Equations (1) and (2), the total income of group i is denoted as:

$$\underset{q_i}{max}\Pi_{iY} = [P(Q) - c_i(x_i,\, x_j)]\, q_i + h_i(f_i,\, f_j)\, R \tag{4}$$

$\forall\; j \neq i, i = 1, 2$

The Nash-Cournot equilibrium can be computed to be

$$q_i \;=\; \frac{d - 2c_i(x_i,\, x_j) + c_j(x_i,\, x_j)}{3b}\,. \tag{5}$$

This result indicate that the existence of spillovers imply that one group's cost reduction effort affects the production decision of the other.

3.2 The first stage

In the first stage of the game, each group i has an endowment E_i to be allocated between cost-reducing R&D investments in the productive sector and resource rent appropriation. It is assumed that this endowment is fixed and exogenously given. Thus, if groups spend more in contesting for rents, then less is available for process innovation in the productive sector.

Given (5), Equation (4) can be written as

$$\underset{x_i}{max}\,\Pi_{iY}(x_i,\, x_j,\, R) \;=\; \frac{[d - A + (2-\beta)x_i + (2\beta - 1)x_j]^2}{9b} \;+\; \frac{f_i}{f_i \,+\, f_j}R \tag{6}$$

$$s.t. \qquad x_i + f_i \leq E_i \, , \;\; x_i \, , \, f_i \geq 0 \tag{7}$$

As shown in Section 4, depending on the value of R, there can either be an interior or a corner solution. Assuming natural resources are below a given threshold, group i maximizes (6) with respect to x_i such that R&D effort is positive. However, if R is too high, there might be no incentive to innovate and the endowment is fully devoted to appropriation.

4 Equilibrium

Define $(x^N, \, f^N)$ as the strategies chosen by the group. The R&D investment and resource rent appropriation effort levels in the interior equilibrium are denoted as in Proposition 1.

Proposition 1:

1. There exists a unique, symmetric subgame perfect equilibrium $(x^N, \, f^N)$ *with*

$$x^N \;=\; \frac{1}{2}[E + \frac{A-d}{\beta+1} \; + \; \sqrt{\triangle(R)}\,] \tag{8}$$

$$f^N \;=\; \frac{1}{2}[E + \frac{d-A}{\beta+1} \; - \; \sqrt{\triangle(R)}\,] \tag{9}$$

$$with \;\triangle(R) = [E + \tfrac{(d-A)}{\beta+1}]^2 - \tfrac{9bR}{2(\beta+1)(2-\beta)}$$

if and only if $R < R_A$ *with* $R_A = [E + \frac{(d-A)}{\beta+1}]^2[\frac{2(\beta+1)(2-\beta)}{9b}.$

2. When $R > R_A$, *a corner solution exists:* $(x^Z, \, f^Z) = (0, \, E)$.

Proof: See Appendix A.1. □

In the interior equilibrium, the arbitrage condition $\frac{\partial \Pi}{\partial x} = \frac{\partial \Pi}{\partial a}$ is fulfilled. That is, the marginal benefit of R&D investment (say, higher profits in the formal sector) is equal to the marginal opportunity cost (i.e. the potential returns from rent contesting). The results in Part 1 of Proposition 1 imply that the allocation of endowment must be such that no group wishes to shift between activities. Meanwhile, Part 2 shows that a corner solution may exist because investments in the two activities are bounded below by zero and above by the endowment. Indeed, it is possible that groups do not invest in R&D at all. When the level of natural resources is extremely high, the incentive to appropriate rents eliminates all investment in R&D. Groups' intial endowments are completely reallocated toward contesting for natural resources. Indeed, the two aforementioned scenarios denote the levels of investment when groups play non-cooperatively in both stages of the game. Nevertheless, the case where groups coordinate their allocative decisions in the first stage, i.e. $(x^O, f^O) = (E, 0)$, can also be considered. When there is cooperation as in Hodler (2006), the groups each gain an equal share of the resource.

Given the R&D and the appropriation investments (x, f) exhibited above, the unit cost c, total output Q, price $P(Q)$, aggregate income 2Π, consumer surplus CS, and social welfare W of the economy can be characterized in Table 1. For ease of reading assume that $E + \frac{d-A}{\beta+1} = \Omega$, $E - \frac{d-A}{\beta+1} = \Psi$, and $E + \frac{d+A}{\beta+1} = \Phi$.

Table 1: Summary of results for each potential equilibria.

	Interior Solution	*Corner Solution*	*Cooperative Solution*
x	$\frac{1}{2}[\Psi + \sqrt{\triangle(R)}]$	0	E
f	$\frac{1}{2}[\Omega - \sqrt{\triangle(R)}]$	E	0
c	$A - \frac{(\beta+1)}{2}[\Psi + \sqrt{\triangle(R)}]$	A	$A - E(\beta+1)$
Q	$\frac{2}{3b}[d - \frac{1}{2}(\beta+1)[\Phi - \sqrt{\triangle(R)}]$	$\frac{2}{3b}(d-A)$	$\frac{2}{3b}(\beta+1)\Omega$
$P(Q)$	$d - \frac{2}{3}[d - \frac{1}{2}(\beta+1)[\Phi - \sqrt{\triangle(R)}]]$	$d - \frac{2}{3}(d-A)$	$d - \frac{2}{3}(\beta+1)\Omega$
2Π	$R + \frac{1}{18b}[(\beta+1)[\sqrt{\triangle(R)} + \Psi]]^2$	$R + \frac{2(d-A)^2}{9b}$	$R + \frac{2[(\beta+1)\Omega]^2}{9b}$
CS	$\frac{2}{9b}[\frac{(\beta+1)}{2}(\Omega + \sqrt{\triangle(R)})]^2$	$\frac{2(d-A)^2}{9b}$	$\frac{2[(\beta+1)\Omega]^2}{9b}$
W	$R + \frac{1}{9b}[(\beta+1)(\Omega + \sqrt{\triangle(R)})]^2$	$R + \frac{4(d-A)^2}{9b}$	$R + \frac{4[(\beta+1)\Omega]^2}{9b}$

Groups are worse-off when they fail to cooperate in R&D provision. Compared to the cooperative solution, the results in the interior equilibrium show that R&D investments are lower, appropriation is intensified, unit cost is higher, the total quantity produced is less, and the price is higher. Indeed, when groups play non-cooperatively, aggregate income, consumer surplus, and welfare are lower compared to the cooperative situation. Outcomes worsen when the natural resource rents are extremely high and neither group invests in cost-reducing innovation.

5 Comparative statics

Focusing on the interior equilibrium, this part discusses the various effects of a marginal change in natural resource abundance.

The effects of an increase in the resource rents on innovation efforts and production in the formal sector are summarized in the following proposition:

Proposition 2: *An increased amount of natural resources reduces cost-reducing R&D investments and output in the productive sector. Thus,*

1. $\frac{\partial x^N(R)}{\partial R} < 0$, *and*
2. $\frac{\partial q^N(R)}{\partial R} < 0$.

The intuition for the first result is pretty straightforward. More natural resources entails a higher common pool prize. *Ceteris paribus*, a marginal increase in appropriation investment may imply higher returns in the informal sector. This makes resource rent grabbing more attractive to both groups. Hence, they shift their initial endowment away from the R&D activity. This might be further intensified by the "free-riding-due to-spillovers effect". Knowing that they can benefit from the R&D investment of their rival, groups may opt to free ride instead. Meanwhile, the second part of Proposition 2 shows that natural resources have an adverse impact in output. Groups engage in less productive activities in the formal sector. When R increases, the quantity produced in the second stage declines because the unit cost is higher. The formal sector's aggregate output eventually falls. Consequently, the price rises as $\frac{\partial P(Q)}{\partial R} = -2b\frac{\partial q^N(R)}{\partial R} > 0$. With these findings, an increase in R obviously has implications on income.

Proposition 3: *Income is negatively correlated to* R *if and only if* $R > R_B = \frac{16(2-\beta)^2(\beta+1)(1-\beta)}{3(7-5\beta)^2}[E + \frac{d-A}{\beta+1}]^2$. *That is,*

1. $\frac{\partial \Pi_Y^N(R)}{\partial R} < 0$.

Proof: See Appendix A.2. □

With $R_A > R_B$, an interior solution is guaranteed. Thus, Proposition 3 suggests innovative results related to the resource curse. The impact of a marginal increase in the natural resource can be decomposed into a positive income effect and a negative diversion effect. Each group's aggregate income decreases only when natural resource rents are high enough, i.e. when the income effect's magnitude (positive) is less than that of the diversion effect (negative). That is, the resource curse occurs when:[7]

$$\frac{\partial \Pi_Y^N(R)}{\partial R} = \frac{\partial \Pi_R^N(R)}{\partial R} + \frac{\partial \Pi_M^N(R)}{\partial R} < 0$$

The existence of a threshold natural resource level is different from the usual findings in recent static papers on rent-seeking/conflict and the resource curse (refer again to Torvik (2002); Hodler (2006); and Wick and Bulte (2006)). In the absence of property rights, these studies observed that there is an unconditional negative relationship between resource abundance and income. An increase in the amount of natural resources always decreases the total income of rivalling groups. The results in this study, however, imply that income only decreases if R is above a given threshold.

As stated above, this paradoxical finding can be explained by decomposing the two effects of natural resource abundance on total income. Indeed, these two opposing effects determine whether a resource curse exists or not[8]. Proposition 3 shows that the resource curse only happens when the "indirect diversion effect" has a greater magnitude compared to the "direct income effect" of the resource boom. The immediate, direct income impact of a higher natural resource rent is a symmetrically proportional (i.e. 0.5) marginal increase in a group's income. Hence, it is a one to one increase in the economy's aggregate income. On the other hand, the indirect diversion effect reduces income as investments are reallocated from cost-reducing R&D to rent appropriation. This displacement of allocative investment can also be analyzed using the combined responses of both price and quantity. Recalling the payoffs for the productive formal sector, the price and quantity effects of a natural resource boom can be decomposed as follows: $\frac{\partial q(R)}{\partial R}(P(Q) - c(x)) + (\frac{\partial P(Q)}{\partial R} - \frac{\partial c(x)}{\partial R})q$. The first term is negative as

[7]The result is the same when the aggregate income of the economy is considered. In this paper, the aggregrate income of both groups is just equal to twice the "total income" of each group.

[8]Following static decentralized models (Torvik (2002); Wick and Bulte (2006); Holder (2006), Mehlum, et al. (2006), etc.), this paper defines the "resource curse" as a fall in income due to an increase in natural resources wealth.

shown in Proposition 1. The second term is also negative since $\frac{\partial P(Q)}{\partial R} < \frac{\partial c(x)}{\partial R}$. Therefore, profits from the formal sector is always negatively correlated with R. The negative impact of a decline in output (and the increase in unit cost) far outweighs the price increase. When this diversion effect is greater than the income gains from the informal sector, the total income of each group (and the aggregate income of the economy) falls with R.

To integrate the discussion, the resource curse indeed follows when the diversion effect dominates the income effect. When part of the initial endowment is displaced away from the R&D activity, the group foregoes a potential increase in income from the formal sector. Nonetheless, it obtains an additional share of the common pool. When $\frac{\partial \Pi_Y^N(R)}{\partial R} = \frac{\partial \Pi_R^N(R)}{\partial R} + \frac{\partial \Pi_M^N(R)}{\partial R} = 0$ and $R = R_B$, these two opposing forces are equal. Thus, with higher R the additional rents in the informal sector obviously go up. Groups are then induced to switch to contesting until a new equilibrium is reached.

Meanwhile, Peretto (2012) emphasized that the literature on the resource curse should not presume that income growth is equivalent to welfare. Providing contrasting support, this study now develops a static, yet convincing finding that the impact of a resource boom on income and welfare differ. As to be explained later on, the negative correlation between natural resources and welfare comes first when rents are above a given threshold, R_C. The peak of the relationship between natural resources and income only happens when $R > R_B > R_C$. Defining welfare as the sum of the groups' income and consumer surplus, Proposition 4 formalizes this result.

Proposition 4: *Depending on the initial amount of natural resources and the extent of spillovers, an increase in resource rents may negatively affect welfare.*
1. If $R > R_B$, $\frac{\partial W(^N R)}{\partial R} < 0$,
2a. If $R < R_B$ *and* $0 < \beta < 0.5$, *then* $\frac{\partial W^N(R)}{\partial R} < 0$,
2b. Finally, when $0.5 \leq \beta < 1$, $\frac{\partial W^N(R)}{\partial R} < 0 \; iff \; R > R_C = \frac{-8(2\beta-1)(2-\beta)[E(\beta+1)+(d-A)]^2}{81b(\beta+1)(1-\beta)^2}$.

Proof: See Appendix A.3. □

As shown in Table 2, focus is given to the scenario where the parameter for technological spillovers is $0 < \beta < 0.5$[9]. There exist four regions with different

[9]Except for the non-existence of Region I, the results for the case with high spillovers are almost the same (see Appendix A.3 for more details). A region experiencing a "pure blessing" does not exist when $0.5 \leq \beta < 1$. Thus, the region where there is a "double curse" encompasses

results: Regions I, II, III, and IV. Region I and II reflects the results for Part 2 of Proposition 1. On the other hand, Region III mirrors the results for Part 1.

Table 2: Summary of Results for the Case with Low Spillovers.

Impact of R		$\frac{\partial x^N}{\partial R}$	$\frac{\partial \Pi_Y^N}{\partial R}$	$\frac{\partial W^N}{\partial R}$
Range of R values				
$0 \leq R \leq R_C$		$-$	$+$	$+$
$R_C < R \leq R_B$		$-$	$+$	$-$
$R < R \leq R_A$		$-$	$-$	$-$
$R_A < R$		$x = 0$	$+$	$+$

Region I shows the results for resource-poor economies with very low initial values of R. Starting from resource scarcity, a marginal increase in the amount of natural resources induces groups to allocate some of their endowment to the informal sector. Thus, cost-reducing innovation in the formal sector goes down. Nonetheless, the magnitude of this negative change is not high. In other words, natural resources can be regarded as a "pure blessing". The shift in investments does not immediately result to a decline in either income or welfare. The resulting decline in R&D and output is not sufficiently strong. The initial amount of natural resources is small enough that the resulting income effect of a marginal change in R far outweighs the negative effect of diversion.

In Region II, R remains scarce that groups still have a strong incentive to invest in cost-reducing R&D. This is reflected by the increase in total income even when the amount of of natural resources increase. The income gains from a resource boom is much stronger than the negative displacement effect. Although R&D investments are reduced when R increases, the benefits from more abundant natural resources outweighs this loss. Compared to Region I, social welfare in II falls with an increase in R. Thus, in this case, more natural resources can be regarded as a "pseudo-blessing". This happens because the magnitude of the positive impact of R on the aggregate income is outweighed by the decrease in consumer surplus: $2\frac{\partial \Pi_Y^N(R)}{\partial R} < -\frac{\partial CS^N(R)}{\partial R}$. The gain in income of both groups is not positive enough to compensate for the reinforcing negative effect of both a decrease in output (due to less cost-reducing R&D) and an increase in price.

a greater range of values when the formal sector is characterized by a high degree of technical externalities.

Region III, on the other hand, has almost the same results as in II. What differs is that the total income of each group now decreases with R. A "double curse" is observed as welfare also declines. The impact of higher natural resource rents is negative on both aggregate income (producer surplus) and consumer surplus. As already discussed above, the groups' income levels fall because the negative diversion effect of a resource boom dominates the positive gains in income. Hence, the always negative impact of resource abundance on consumer surplus is amplified. This negative correlation between resource rents and consumer surplus is supported by Proposition 2. Due to lower cost-reducing R&D investments, outputs fall. The decline in the total quantity produced, in turn, increases price $P(Q)$. Consequently, when there is a marginal increase in R, the consumer surplus always decreases. In summary, results for Region III show that groups experience the a double curse. Both income ans welfare fall with a rise in natural resource rents.

Finally, Region IV exhibits the case where the economy is extremely resource-rich and no group has an incentive to invest in R&D. Hence, a corner solution exists. The amount of natural resources in the common pool are too high that all groups allocate their full endowment into appropriation. It is as if the economy is trapped in an innovation-less scenario. Nonetheless, having $x = 0$ as always fixed, a marginal increase in R causes income and welfare (one-to-one increase) to go up.

6 Concluding remarks

A new mechanism explaining why an increase in the amount of natural resources may decrease income and welfare has been developed. Although the model is constructed in the simplest possible way, it captures an interesting idea that a resource boom reduces innovative investments in the economy. This is done by assuming a potential trade-off between cost-reducing R&D and resource rent contesting. Different from results commonly found in existing literature, this study found a non-monotonic relationship between natural resource abundance and aggregate income. A curse occurs only when the initial level of natural resource is sufficiently high. It was observed that natural resources can be a blessing when the income effect dominates the diversion effect. Welfare, on the other hand, almost always decreases during a resource boom.

There are several potential extensions to the current model. First, to provide value-added to the analysis one may suppose asymmetry among more than two groups. Second, a game with dynamic R&D can also be considered. These extensions are parts of the author's future research agenda.

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Appendix A.1: Proof of Proposition 1

Groups maximize Equation (6) with respect to x_i such that constraint (7) is met.

$$\max_{x_i} \Pi_{iY}(x_i,\, x_j,\, R) \;=\; \frac{[d-A+(2-\beta)x_i+(2\beta-1)x_j]^2}{9b} + \frac{E_i - x_i}{E_i\, + E_j\, -\, x_i\, - x_j} R.$$

$$\frac{\partial \Pi_{iY}}{\partial x_i} = \frac{2}{9b}(2-\beta)[(d-A)+(2-\beta)x_i+(2\beta-1)x_j] + \frac{-R(E_i+E_j-x_i-x_j)+R(E_i-x_i)}{(E_i+E_j-x_i-x_j)^2}$$

Assuming symmetry among groups,

$$\frac{\partial \Pi_{iY}}{\partial x_i} \;=\; \frac{2}{9b}(2-\beta)[(d-A)+(\beta+1)x] \;-\; \frac{R}{4(E-x)} \;=\; 0$$

$$\Leftrightarrow x^2 - [E + \frac{A-d}{\beta+1}]x + \frac{1}{\beta+1}[\frac{9bR}{8(2-\beta)} + E(A-d)] \;=\; 0$$

To ensure that cost-reducing R&D effort x_i is non-negative, the following condition (necessary and sufficient) must be met: $\triangle(R) \;=\; [E + \frac{(d-A)}{\beta+1}]^2 - \frac{9bR}{2(\beta+1)(2-\beta)} \;>\; 0$. If $\triangle(R){>}0$, then $x{>}0$ if natural resource rents are below a given threshold R_A. Otherwise, $x\,=\,0$ (i.e. nobody invests in R&D) and the initial endowment is fully devoted to appropriation, $E = f$. More specifically, the following should be satisfied to ensure the R&D efforts are positive: $R_A \;= [E + \frac{(d-A)}{\beta+1}]^2[\frac{2(\beta+1)(2-\beta)}{9b}] \;>\; R.$

Appendix A.2: Proofs regarding the effect on a marginal change in R on total income.

Total income is given by $\Pi_Y(R) \;=\; \Pi_R(R) + \Pi_M(R)$. Thus, $\Pi_Y(R) \;=\; \frac{R}{2} + \frac{[(d-A)+(\beta+1)x^*]^2}{9b} = \frac{R}{2} + \frac{1}{36b}[(\beta+1)(E+\sqrt{\triangle(R)}) - (A-d)]^2$.

Differentiating this with respect to R ,

$$\frac{\partial \Pi_Y(R)}{\partial R} \;=\; \frac{\partial \Pi_R(R)}{\partial R} \;+\; \frac{\partial \Pi_M(R)}{\partial R}$$

$$\Leftrightarrow \underbrace{\frac{1}{2}}_{direct\,income\,effect\,from\,the\,resource\,boom} + \underbrace{\frac{2}{9b}[(d-A)+(\beta+1)x](\beta+1)\frac{\partial x}{\partial R}}_{indirect\,diversion\,effect}$$

$$\Leftrightarrow \frac{1}{8\sqrt{\triangle}(2-\beta)}[\sqrt{\triangle}(7-5\beta)-[(\beta+1)E-(A-d)]]$$

To determine the sign of $\frac{\partial \Pi_Y(R)}{\partial R}$, the sign of the last term must be known. For the resource curse to occur, it must be negative. That is, $\sqrt{\triangle}(7-5\beta) < (\beta+1)E-(A-d)$ must hold. $\frac{\partial \Pi_Y(R)}{\partial R} < 0$ if the following condition is satisfied: $0 < R_B = \frac{16(2-\beta)^2(\beta+1)(1-\beta)}{3(7-5\beta)^2}[E+\frac{d-A}{\beta+1}]^2 < R$.

Appendix A.3: Proofs regarding the effect on a marginal change in R on welfare.

1. When $\frac{\partial \Pi_Y(R)}{\partial R} < 0$, $\frac{\partial W(R)}{\partial R} < 0$ always occurs. Note that $\frac{\partial W(R)}{\partial R} = 2\frac{\partial \Pi_Y(R)}{\partial R} + \frac{\partial CS(R)}{\partial R}$. With $\frac{\partial CS(R)}{\partial R} < 0 \forall R$ and $\frac{\partial \Pi_Y(R)}{\partial R} < 0$ if $R_B < R$, then $\frac{\partial W(R)}{\partial R} < 0\, iff\; R_B < R$.

2. When $\frac{\partial \Pi_Y(R)}{\partial R} < 0$, $\frac{\partial W(R)}{\partial R} < 0$ only happens when certain conditions regarding the magnitude of cost-reducing R&D externalities are met. Given that it is always $\frac{\partial CS(R)}{\partial R} < 0$, it is still possible to have $\frac{\partial W(R)}{\partial R} < 0$ even if $\frac{\partial \Pi_Y(R)}{\partial R} > 0$. This is true if $2\frac{\partial \Pi_Y(R)}{\partial R} < -\frac{\partial CS(R)}{\partial R}$. Equivalently, this occurs when $R_C = \frac{-8(2\beta-1)(2-\beta)[E(\beta+1)+(d-A)]^2}{81b(\beta+1)(1-\beta)^2} < R$.

The left-hand side is negative if $0.5 \leq \beta < 1$. In this case, $R > 0$ is always satisfied. Therefore, when $0.5 \leq \beta < 1$ (i.e. when technological spillovers are very high), welfare is always negatively correlated with the amount of natural resources. If $0 < \beta < 0.5$ (low extent of spillovers), R should be higher a given threshold, to induce a fall in welfare.

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