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Rapacious Resource Depletion, Excessive Investment and Insecure Property Rights

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RAPACIOUS RESOURCE DEPLETION, EXCESSIVE INVESTMENT AND INSECURE PROPERTY RIGHTS

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Abstract

For a country fractionalized in competing factions, each owning part of the stock of natural exhaustible resources, or with insecure property rights, we analyze how resources are transformed into productive capital to sustain consumption. We allow property rights to improve as the country transforms natural resources into capital. The ensuing power struggle about the control of resources is solved as a non-cooperative differential game. Prices of resources and depletion increase faster than suggested by the Hotelling rule, especially with many competing factions and less secure property rights. As a result, the country substitutes away from resources to capital too rapidly and invests more than predicted by the Hartwick rule. The power struggle boosts output but depresses aggregate consumption and welfare, especially in highly fractionalized countries with less secure property rights. Genuine saving evaluated with welfare-based accounting prices is zero in this game, but biased upwards if calculated with the lower market prices.

JEL code: E20, F32, O13, Q01, Q32

Keywords: Exhaustible resources, Hotelling rule, Hartwick rule, capital, sustainable consumption, fractionalization, seepage, insecure property rights, differential game

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1. Introduction

The idea that rents from exhaustible natural resources should be saved and reinvested in productive capital is common in policy circles. It has first been formalized by Hartwick (1977) within the context of the canonical closed economy model of resource extraction, capital formation, consumption and growth developed by Solow (1974). With Cobb-Douglas production, the capital stock grows at a linear rate with the saving rate equal to the constant share of exhaustible natural resource in value added, all rents from resources are reinvested and consumption is sustained at a constant level. This way of transforming exhaustible natural resources into productive capital has become known as the Hartwick rule. [2] To obtain this result, prices of natural resources must grow at the market rate of interest for the country to be indifferent between keeping natural resources in the ground or depleting them and obtaining a market return. This is, of course, the Hotelling rule first stated by Hotelling (1931).

Our principle objective is to derive political counterparts of the Hartwick and Hotelling rules by extending the analysis of Solow (1974) and Hartwick (1979) to a fractionalized economy, i.e., an economy with competing factions, each owning part of the nation's stock of exhaustible natural resources. Ownership rights on the stock owned by each group are, however, not secure. This may be due to seepage, which occurs if the oil, gas or water reserves in any field are connected with other fields.[3] This introduces a dynamic common-pool problem, especially if seepage is substantial. Effectively, competing factions extract natural resources too fast for fear of their reserves seeping to other fields. However, our main focus is on how economic development leads to better property rights and thus to less infringement of property rights. The degree to which individual fields can be encroached by others thus decreases with economic development.

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[2] Dixit, Hammond and Hoel (1980) and Dasgupta and Mitra (1983) discuss the Hartwick rule from the point of view of max-min egalitarianism. However, with a positive elasticity of intertemporal substitution, private consumption will not be constant. If consumption is initially held below its max-min level, capital is accumulated sufficiently fast to ensure that later generations enjoy increasing levels of consumption. While resource use declines to zero, unlimited growth in consumption and output is feasible. The Euler equation for consumption growth implies that, as long as the rate of time preference is strictly positive, the capital stock must ultimately go to zero to ensure that growth in private consumption is non-negative. It is thus optimal to let consumption, output and capital vanish in the long run even though it is feasible to avoid such a doomsday scenario. Future generations are thus doomed. From a utilitarian perspective this does not matter as the benefit to early generations exceeds the loss to later generations. Obviously, it is hard on ethical grounds to defend such an outcome. This is why the max-min egalitarian outcome seems preferable.

[3] Over-pumping of water out of once plentiful groundwater aquifers for irrigation purposes is one of the main reasons for water shortages from the High plains of the United States to the Gangetic Plain of northern India to Australia (Sachs, 2008). Due to seepage and the unregulated and indiscriminate access to groundwater resources, much of this over-pumping arises from a classic common-pool problem. Over-pumping causes not only water shortages, but also leads to contamination with salt water, poisoning and collapse of aquifers.

We thus offer a political economy explanation of why fractionalized resource-rich countries deplete their natural resources faster and end up with lower levels of sustainable consumption than homogenous societies, especially if property rights are more insecure. Each one of the rival groups tries to deplete their natural resources before it seeps away or is grabbed by other groups. Since property rights for natural resources are badly defined, the power struggle becomes more intense and makes competing groups more impatient. As a result, the country depletes natural resources faster than dictated by the Hotelling rule. Fractionalized countries substitute away from natural resources to capital in production at a too rapid rate so that they save and invest more than a homogenous society. We show that fractionalization into different resource-owning groups and less secure property rights drive the non-cooperative saving rate above the production share of natural resources. The interest rate and the output-capital ratio gradually fall to zero. The power struggle thus boosts output. Nevertheless, due to the higher savings rate, fractionalization and less secure property rights depress aggregate consumption and social welfare, especially if there are many rival factions and property rights are less secure.

We also establish that genuine saving is zero in a fractionalized society with insecure property rights if, following Arrow, Dasgupta and Mäler (2003), proper welfare-based accounting prices are used to value the cost of resource depletion. This accounting price corresponds to the market price that would prevail in a homogenous society, and is therefore higher than the market price that prevails in a fractionalized society. Zero genuine saving occurs, because the too rapid depletion of natural resources is in line with the too rapid accumulation of physical capital by each group. Since the correct accounting price that must be used to calculate genuine saving exceeds the market price, the cost of resource depletion is under-estimated if market prices instead of accounting prices are used. This suggests that negative genuine saving estimates reported by the World Bank for many resource-rich countries may be even more negative.

Our general equilibrium analysis is related to the earlier literature on oligopoly extraction of a common property natural resource in partial equilibrium, which stresses the importance of the period of commitment and the importance of the feedback Nash and the open-loop Nash equilibrium solutions (e.g., Reinganum and Stokey, 1985; van der Ploeg, 1987; Karp, 1992). The main insight of this literature is that in a non-cooperative context groups tap the common stock of natural resources more quickly, especially if the period of commitment is short as in the feedback Nash equilibrium solution where the period of commitment is zero. We focus, however, on the open-loop Nash equilibrium solution for three reasons. First, under this solution concept an economy with infinite seepage and no property rights turns out to be Pareto efficient, but this is not the case with seepage and imperfect property rights. We are thus able to focus at the inefficiencies caused by finite seepage rates and less than perfect property rights and analyze how this affects the rate at which natural resources are being tapped. Second, the open-loop Nash equilibrium solution allows closed-form solutions numerical simulation. Third, our main objective is to analyze how the Hartwick rule of reinvesting the Hotelling scarcity rents into various forms of productive capital is affected under open-access natural resources or fields of natural resources owned by different groups but suffering from common-pool problems due to seepage of natural resources or imperfect property rights.

Our analysis is also related to that of the voracity effect in societies with competing groups and lack of effective property rights. Lane and Tornell (1996) and Tornell and Lane (1999) have demonstrated that a higher raw return on a common asset than on private assets increases the extent of rent seeking and thus curbs the rate of economic growth and makes a country worse off. The voracity effect also arises from a dynamic common-pool problem, whereby each group tries to grab more of the common asset before the other groups do so. We extend van der Ploeg (2008) who studies genuine saving and voracious depletion within the context of a model with a pure common exhaustible natural resource and no property rights at all on natural resources. The main contribution of this paper is thus to allow each group to own its own stock of natural resources while property rights are neither perfect nor completely absent. Instead, property rights become more secure as the country accumulates more productive capital.

The outline of the paper is as follows. Section 2 sets up our model of depletion of exhaustible natural resources by competing factions and private accumulation. Section 3 gives the optimality conditions for the open-loop Nash equilibrium outcome of the non-cooperative differential game. Section 4 shows how the maxi-min outcome for this game permits an outcome with constant levels of consumption and output and characterizes the results. Section 5 discusses the homogenous case without competing factions or, alternatively, the case with no seepage and perfectly secure property rights on natural resources. This results in the familiar apolitical Hotelling and Hartwick rules where all resource rents are reinvested. Section 6 discusses why in a fractionalized society, prices of natural resources increase too fast, depletion occurs too fast, savings and output are too high, and consumption is too low, especially if there are many competing factions and the quality of property rights is bad. Section 7 establishes that genuine saving is zero in societies with competing factions in society or imperfect property rights if welfare-based accounting prices are used to evaluate the cost of resource depletion. Section 8 discusses the negative genuine saving estimates reported by the World Bank for many resource-rich economies and argues that even these may be too optimistic if market prices are used instead of accounting prices. Section 9 qualifies the results and concludes.

2. Competing Factions, Resource Depletion and Capital Accumulation

We set up a model of a closed economy where the national stock of exhaustible natural resources is owned by rival factions who invest in private capital and manage their own stock of natural resource in the face of imperfect property rights. There is no population growth. Each group combines use of its exhaustible resources together with capital (and possibly labor and other factor inputs in fixed supply) to produce output according to a Cobb-Douglas production function. To focus on the interactions between asset accumulation and depletion of exhaustible resources, we abstract from trade between the various groups in society. We also abstract from open economy considerations such as natural resource exports, imports of produced goods, and investment in foreign assets.[4]

There are thus N rival groups who struggle for power over the control of natural resources. The depletion of the stock exhaustible natural resource reserves of group i is represented by the following diffusion process:

(1) $$\dot{S}_i = -R_i - \sum_{j \neq i}^{N} \xi (S_j - S_i), \quad S_i(0) = S_{i0}, \; i = 1,..,N,$$

where R_i and S_i denote, respectively, the depletion rate and the stock of remaining natural resource reserves of group i. The parameter $\xi \geq 0$ indicates the speed of seepage between the various oil or gas fields or the various linked water aquifers owned by the different groups. If $\xi = 0$, there is no seepage and the oil, gas or water reserves are physically completely separate. In that case, there are no elements of a common-pool problem. This may be realistic for exhaustible gold, silver, diamond and iron deposits, but not for oil, gas or water deposits. In practice, if a neighbor pumps up a lot of oil, gas or water and has lower stocks of reserves, then oil, gas or water will seep away to the neighbor's field or aquifer. We focus on the importance of property rights for resource depletion and capital accumulation and thus set $\xi \equiv \xi^*/K$, where $\xi^* \geq 0$ indicates the given initial degree of insecurity of property rights and K the aggregate capital stock. This captures that quality of property rights improves as societies become more advanced and have bigger stocks of aggregate capital. The parameter ξ thus indicates the ease by which property rights on natural resources can be encroached. Since property rights on natural resource

[4] Within the context of a two-sector general equilibrium model of a small open economy, opening up to trade induces instantaneous gains from trade but these are eroded by ongoing natural resource depletion and the steady-state level of utility is lower than under autarky (Brander and Taylor, 1997). Within the context of a two-good, two-country world with national open-access renewable resources, natural resource importers gain from trade while a diversified natural resource exporter suffers a decline in steady-state

stocks are insecure, we have features of a common-pool problem. Integration of (1) shows that the time path of exhaustible resource depletion must satisfy:

$$(1') \qquad \int_0^\infty \left[R_i(t) - \sum_{j \neq i} \xi\left(S_j(t) - S_i(t)\right) \right] \mathrm{d}t \leq S_{i0}, \quad i = 1, \ldots N$$

where t denotes time and S_{i0} the initial stock of natural resource reserves owned by group i. Note that for the aggregate economy, the resource depletion equations become $\dot{S} \equiv \sum_{i=1}^{N} \dot{S}_i = -R$, $S(0) = S_0 \equiv \sum_{i=1}^{N} S_{i0}$, $R \equiv \sum_{i=1}^{N} R_i$ and $\int_0^\infty R(t)dt \leq S_0$, where R stands for aggregate resource depletion and S for the aggregate stock of remaining natural resource reserves.

Each group i also accumulates assets K_i. Since we abstract from adjustment costs, taxes, etc., the relative price of financial assets is unity and their value exactly equals the capital stock. The capital stock of each group can be viewed as physical capital or human capital. Each group i employs capital, natural resources R_i and labor L_i to produce output Y_i. The production function for each group Y_i = F(K_i, L_i, R_i) satisfies the Inada conditions and constant returns to scale. Natural resources are *necessary* for production, so F(K_i, L_i, 0) = 0. Natural resources are also *inessential* for production to avoid that feasible consumption vanishes as natural resources run out. If there are sufficient substitution possibilities between resources and capital or labor, positive levels of output can be generated by switching from resource-intensive to capital-intensive modes of production. With a CES production function, natural resources are neither necessary nor essential if the elasticity of substitution between factors of production exceeds unity. If the elasticity of substitution is less than unity, capital accumulation cannot compensate for the inevitable decline in the use of natural resources. Output and consumption must thus decline to zero. The economy is doomed, so that natural resources are essential for production. We therefore assume that each group has a Cobb-Douglas production function with a unit elasticity of factor substitution and a share of capital in value added greater than that of natural resources, i.e., $Y_i = K_i^\alpha R_i^\beta L_i^{1-\alpha-\beta}, \alpha > \beta > 0, \alpha + \beta < 1$. Natural resources are thus necessary, but not essential for production.[5] We abstract from depreciation of capital. Each group supplies

utility despite some initial gains from trade (Brander and Taylor, 1998). The welfare consequences of opening up to free trade may thus well be negative.

[5] If $\alpha < \beta$, capital does not add enough to production to compensate for the declining use of natural resources and sustain a positive level of consumption. Resources are then essential for production.

inelastically 1/N of labor, so that aggregate labor supply is normalized to one. If consumption by group i is denoted by C_i, the evolution of private wealth of group i is given by:

(2) $$\dot{K}_i = Y_i - C_i, \quad \text{where} \quad Y_i = K_i^{\alpha} R_i^{\beta} L_i^{1-\alpha-\beta} \text{ and } L_i = 1/N.$$

We abstract from extraction costs for natural resources. We derive a Nash equilibrium solution; so that each rival group i when deciding on its optimal depletion level R_i supposes that the depletion levels of the other factions $R_j,\ j \neq i,$ remain constant. If ρ indicates the pure rate of time preference employed by each group, each group i chooses C_i and R_i to maximize its utility

(3) $$U_i = \int_0^{\infty} \mathrm{u}(C_i) \exp(-\rho t) \mathrm{dt}, \quad \mathrm{u}' > 0, \mathrm{u}'' \leq 0,$$

subject to the evolution of its natural resource stock (1), the evolution of its capital stock (2) and the Nash conjecture that the depletion rates by the other groups in society, R_j , $j \neq i$, do not change when deciding on the optimal level of R_i.

3. Optimality Conditions for the Dynamic Common-Pool Problem

We derive for this non-cooperative differential game an open-loop Nash equilibrium solution.[6] The resulting solution will be summarized in Proposition 1. The Hamiltonian for group i maximizing (3) subject to (1) and (2) is defined by

(4) $$H_i \equiv \mathrm{u}(C_i) + \lambda_i \left[K_i^{\alpha} R_i^{\beta} \left(\frac{1}{N} \right)^{1-\alpha-\beta} - C_i \right] - \mu_i \left[R_i - \sum_{j \neq i} \xi \left(S_j - S_i \right) \right],$$

where λ_i and μ_i denote the marginal utility for group i of an extra unit of capital and natural resources, respectively. Application of Pontryagin's maximum principle yields the following first-order conditions for each of the groups:

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[6] In the absence of property rights whatsoever (i.e., $\xi^* \to \infty$), one has an open-access common exhaustible resource whose development is given by $\dot{S} = -\sum_{i=1}^{N} R_i,\ S(0) = S_0$. The open-loop Nash equilibrium outcome then yields the efficient solution which also prevails in a homogenous society without rival factions. The feedback Nash equilibrium yields an inefficient solution with too fast extraction of the common exhaustible resource and sub-optimally low levels of consumption and high levels of saving and output (van der Ploeg, 2008). Our general equilibrium results are akin to earlier results on the efficiency of the open-loop solution for an open-access problem in partial equilibrium when demand for resources is iso-elastic (Reinganum and Stokey, 1985). Note that the Cobb-Douglas production function in our general equilibrium analysis gives rise to a constant elasticity of demand for natural resources as well.

(5)
$$\frac{\partial H_i}{\partial C_i} = \text{u}'(C_i) - \lambda_i = 0, \quad \frac{\partial H_i}{\partial R_i} = \beta \frac{Y_i}{R_i}\lambda_i - \mu_i = 0, \quad \rho\lambda_i - \dot{\lambda}_i = \frac{\partial H_i}{\partial K_i} = \alpha \frac{Y_i}{K_i}\lambda_i \equiv r_i\lambda_i$$
$$\text{and } \rho\mu_i - \dot{\mu}_i = \frac{\partial H_i}{\partial S_i} = -(N-1)(\xi^*/K)\mu_i, \quad i = 1,\ldots,N.$$

The following transversality conditions should also be satisfied:

(6)
$$\lim_{t\to\infty}\left[\exp(-\rho t)\lambda_i(t)K_i(t)\right] = 0 \text{ and } \lim_{t\to\infty}\left[\exp(-\rho t)\mu_i(t)S_i(t)\right] = 0, \quad i = 1,\ldots,N.$$

Equation (5) implies that the marginal product of natural resources $\beta Y_i/R_i$ should equal the price of natural resources, $p_i \equiv \mu_i/\lambda_i$. Furthermore, the marginal product of capital $\alpha Y_i/K_i$ should equal the rate of return on capital for each group r_i. Since in symmetric equilibrium the interest rates and natural resource prices are the same for each group, we drop group subscripts (i.e., $r = r_i$ and $p = p_i$, i=1,…,N) and write these efficiency conditions as:

(7)
$$\frac{\dot{p}}{p} = r + (N-1)\frac{\xi^*}{K} \quad \text{where} \quad p = \beta\frac{Y_i}{R_i}, r = \alpha\frac{Y_i}{K_i}, i = 1,\ldots,N, \text{ and } K \equiv \sum_{i=1}^{N} K_i.$$

Equation (7) is the political variant of the Hotelling rule. If there is no fractionalization of society (i.e., N = 1) or property rights on natural resources are completely secure (ξ^* = 0), equation (7) reduces to the familiar Hotelling rule which states that the expected rate of increase in natural resources should equal the market rate of interest. This follows from the following arbitrage condition. On the margin, society should be indifferent between keeping natural resources under the ground and receiving an expected capital gain $\dot{p}/p$, and digging the resources up, selling them, and investing the proceeds and receiving a rate of return r. Rival groups in society, however, drive a wedge in the Hotelling rule. The reason is that each group consumes more today; they think that if they conserve their resources, their neighbor will consume more tomorrow. [7] This version of the Hotelling rule implies a bigger rate of increase in the price of natural resources than is socially optimal. This distortion appears to be smaller if the groups have

[7] Since any group i takes the extraction rate of the other group $j \neq i$ as given in the open-loop Nash equilibrium, group i does not expect that by delaying her own extraction she causes other groups to extract more of the resource. However, seepage implies that, if extraction is delayed, the stock of i will be higher than that of groups $j \neq i$ and thus more of stock of i will seep to the fields of groups $j \neq i$.

accumulated a lot of non-resource wealth, but in the Nash equilibrium solution with constant levels of consumption and output (derived in section 4) the rate of interest also falls as the capital stock rises over time. Equation (7) thus indicates that the rate of change of natural resource prices is inversely related to the capital stock. It exceeds the rate of interest in a fractionalized society, but over time this intertemporal wedge in the Hotelling rule asymptotically vanishes as society accumulates increasing amounts of capital and property rights improve. We also see from (7) that the political distortions in the Hotelling rule leading to too rapid extraction and too rapid increases in the price of natural resources are more severe if initial property rights are more insecure (higher ξ^*).

First-order conditions (5) also imply the Keynes-Ramsey rule for growth in consumption:

(8) $$\frac{\dot{C}_i}{C_i} = \theta_i \left(r_i - \rho \right), \text{ where } \theta_i \equiv -u'(C_i)/C_i u''(C_i) \geq 0.$$

4. Sustaining Consumption in the Dynamic Common-Pool Problem

Since we are interested in maxi-min egalitarian outcomes with zero elasticities of intertemporal substitution (i.e., $\theta_i = 0$), we look for dynamic general equilibrium paths with constant levels of consumption, $C_i(\mathrm{t}) = C/N > 0$, $\forall \mathrm{t} \geq 0$ with aggregate consumption $C > 0$ a constant to be determined. To obtain a Nash equilibrium solution with constant levels of consumption and output, we suppose a constant savings rate s and hypothesize the feasible program:

(9) $$K_i(\mathrm{t}) = s\, Y_i(t)\, t + K_{i0} > 0, \ \forall \mathrm{t} \geq 0,$$

where for each group i we have that $K_i(0) = K_{i0}$ is the initial private stock of productive capital and the output level of each group $Y_i(t) > 0$ is a positive constant. We will now verify that this hypothesized program (9) indeed satisfies the optimality conditions of the non-cooperative Nash equilibrium (5)-(6) as well as (1)-(2). Since investment is constant in such a program, output of each faction $Y_i(\mathrm{t}) = sY_i\ (t) + C/N$ and aggregate output $Y \equiv \sum_{i=1}^{N} Y_i = sY + C = C/(1-s)$ are constant as well. Making use of the political Hotelling rule (7) and the production function in (2), we obtain

(10) $$\frac{\dot{p}}{p} = \frac{\dot{Y}}{Y} - \frac{\dot{R}}{R} = -\left(\frac{1-\beta}{\beta}\right)\frac{\dot{Y}}{Y} + \left(\frac{\alpha}{\beta}\right)\frac{\dot{K}}{K} = \frac{\alpha Y + \xi^*(N-1)}{K},$$

which gives the savings rate as a diminishing function of aggregate output:

$$(11) \qquad s \equiv \frac{\dot{K}}{Y} = \beta\left[1 + \frac{\xi^*(N-1)}{\alpha Y}\right] \geq \beta.$$

This is a political variant of the Hartwick rule, which says that a fractionalized economy with insecure property rights saves more than its natural resource rents. This wedge in the political Hartwick rule is bigger in societies with lower levels of output, worse property rights and a larger number of rival factions. The apolitical Hartwick rule, in contrast, applies to a homogenous society or one with perfect property rights and states that all revenues from natural resource should be reinvested, so that $s = \beta$. We note from (10) and $R = Y^{1/\beta}K^{-\alpha/\beta}$ that

$$(12) \qquad \frac{\dot{R}}{R} = -\frac{\alpha}{\beta}\frac{\dot{K}}{K} = -\frac{\alpha sY}{\beta K} \quad \text{or} \quad \dot{R}(t) = -\left(\frac{\alpha}{\beta}\right) sY^{\frac{1+\beta}{\beta}}(K_0 + sYt)^{-\left(\frac{\alpha+\beta}{\beta}\right)}.$$

Integrating (12) and solving for the aggregate level of natural resource depletion yields

$$(12') \qquad R(t) = R(0) - \left[K_0^{-\alpha/\beta} - \left(K_0 + sYt\right)^{-\alpha/\beta}\right]Y^{1/\beta} = \left(K_0 + sYt\right)^{-\alpha/\beta} Y^{1/\beta},$$

where the second identity follows from using the production function. The equilibrium solution must asymptotically deplete all natural resources, since any unused resources can be used to boost the sustainable level of consumption of any group. The solution must thus satisfy (1′) with equality. Using (12′), this implies that

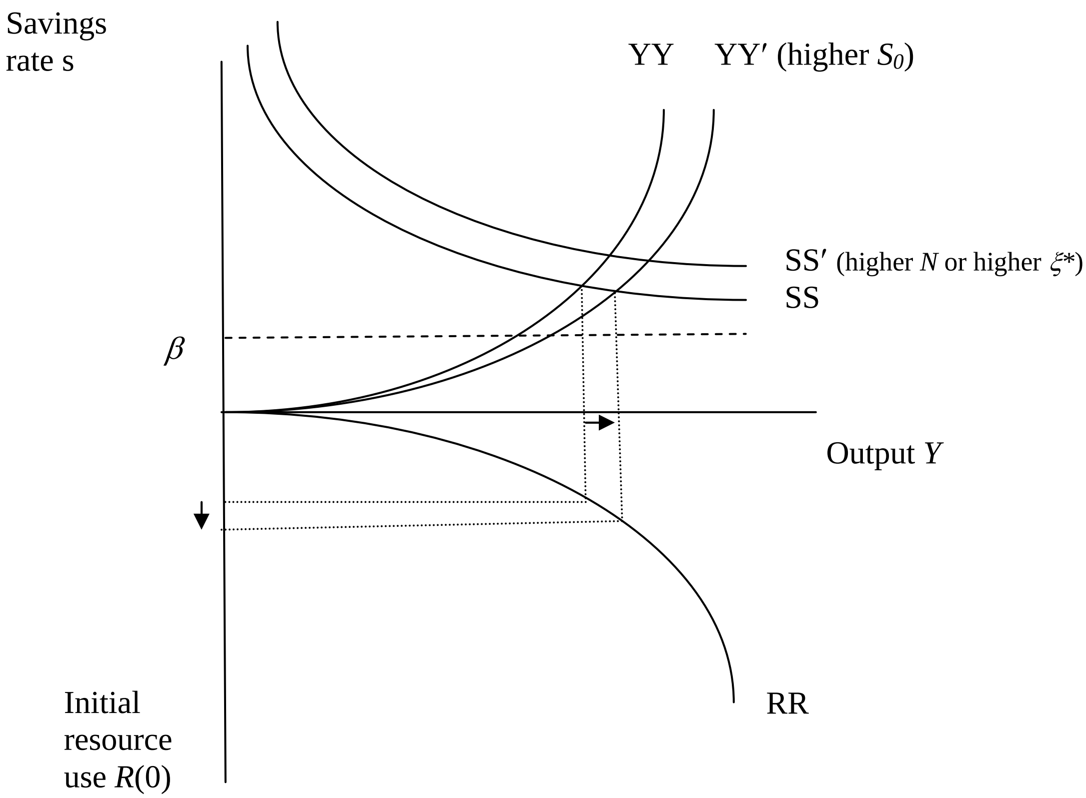
$$(13) \qquad S_0 = Y^{\frac{1}{\beta}} \int_0^\infty \left(K_0 + sYt\right)^{-\alpha/\beta} \mathrm{d}t = \left(\frac{\beta}{\alpha-\beta}\right) \frac{Y^{\frac{1-\beta}{\beta}}}{sK_0^{\frac{\alpha-\beta}{\beta}}}.$$

Equation (13) yields the aggregate level of output and, using $R(0) = Y^{1/\beta}K_0^{-\alpha/\beta}$, also aggregate use of natural resources, both as increasing functions of the savings rate:

(14) $$Y=\left[s\left(\frac{\alpha-\beta}{\beta}\right)K_0^{\frac{\alpha-\beta}{\beta}}S_0\right]^{\frac{\beta}{1-\beta}} \text{ and } R(0)=\left[s\left(\frac{\alpha-\beta}{\beta}\right)K_0^{-(1-\alpha)}S_0\right]^{\frac{1}{1-\beta}}.$$

A higher initial stock of natural resources permits a higher level of output and thus necessitates a higher level of initial resource depletion. A higher stock of productive capital also permits more production, but requires a lower level of initial resource depletion. A higher savings rate boosts output and thus boosts initial resource use as well.

Figure 1: Solving for aggregate output, initial resource use and the savings rate



Key: More fractions or less secure property rights shift the savings locus from SS to SS′, so the savings rate, output and initial resource use increase. A higher stock of initial natural resource reserves shifts the output locus YY to YY′, so the savings rate falls while output and initial resource use increase.

The Nash equilibrium solution can be obtained by solving (11) and (14). Figure 1 uses the downward-sloping savings locus (11) denoted by SS and the upward-sloping output locus (14) indicated by YY together with the initial resource use locus RR defined by $R(0)=Y^{1/\beta}K_0^{-\alpha/\beta}$ to solve for the equilibrium savings rate, aggregate output and the initial rate of resource depletion.

We see that a higher initial stock of capital or higher initial reserves of natural resources allows higher levels of production, for a given savings rate, and thus shifts out the output locus. As a result, the economy ends up with a higher level of output, a lower savings rate and a higher level of sustainable consumption. We see that a bigger initial stock of natural resources boosts the initial rate of resource depletion and lifts up the whole trajectory of resource depletion while a higher initial stock of productive capital can be shown to reduce the initial rate of natural resource depletion. On the other hand, more competing factions in society or less secure property rights on natural resources drive a wedge in the political Hartwick rule (11) and thus shift up the saving locus. It follows that society ends up with a higher savings rate and a higher level of output. Despite the higher output, a more fractionalized society or a society with less secure property rights sustains a lower level of consumption. It is also clear that the initial rate of natural resource depletion is higher, which is a consequence of the more rapid increase in natural resource prices and more rapacious resource depletion. We now establish the properties of the Nash equilibrium solution more formally.

Proposition 1: The open-loop Nash equilibrium solution is characterized by a constant savings rate and constant levels of sustainable consumption and output:

(15) $$s = \mathrm{s}\left(\overset{-}{K}_0, \overset{-}{S}_0, \overset{+}{\xi}*, \overset{+}{N}\right), \quad Y = \Upsilon\left(\overset{+}{K}_0, \overset{+}{S}_0, \overset{+}{\xi}*, \overset{+}{N}\right) \text{ and } C = \mathrm{C}\left(\overset{+}{K}_0, \overset{+}{S}_0, \overset{-}{\xi}*, \overset{-}{N}\right).$$

The transformation of exhaustible natural resources into productive capital to sustain constant levels of consumption and production requires a declining stock of natural resource reserves,

(16) $$S(t) = S_0 \left[\frac{K_0 + \Upsilon\left(\overset{+}{\xi}*, \overset{+}{N}\right) t}{K_0} \right]^{-\left(\frac{\alpha-\beta}{\beta}\right)} \rightarrow 0 \quad \text{as} \quad \mathrm{t} \rightarrow \infty,$$

and a linearly increasing trajectory of the aggregate capital stock

(17) $$K(t) = K_0 + \Upsilon\left(\overset{+}{\xi}*, \overset{+}{N}\right) t,$$

where $sY \equiv \Upsilon\left(\overset{+}{\xi}*,\overset{+}{N}\right)$ denotes national savings. The declining path of natural resource use is:

(18) $$R(t) = \left[K_0 + \Upsilon\left(\overset{+}{\xi}*,\overset{+}{N}\right)t\right]^{-\left(\frac{\alpha}{\beta}\right)} \Upsilon\left(\overset{+}{K}_0,\overset{+}{S}_0,\overset{+}{\xi}*,\overset{+}{N}\right)^{\frac{1}{\beta}} \text{ with } R(0) = \mathrm{R}\left(\overset{-}{K}_0,\overset{+}{S}_0,\overset{+}{\xi}*,\overset{+}{N}\right).$$

Prices of natural resources $p = \beta Y/R$ increase forever; initially they increase at a faster pace than the market rate of interest, especially if ξ^* $(N–1)$ is large, but this wedge vanishes asymptotically:

(19) $$p(t) = \beta\Upsilon\left(\overset{+}{K}_0,\overset{+}{S}_0,\overset{+}{\xi}*,\overset{+}{N}\right)^{1-1/\beta}\left[K_0 + \Upsilon\left(\overset{+}{\xi}*,\overset{+}{N}\right)t\right]^{\alpha/\beta} \text{ and}$$
$$\frac{\dot{p}(t)}{p(t)} = r(t) + \frac{\xi^*(N-1)}{K(t)} = \frac{\alpha\Upsilon\left(\overset{+}{\xi}*,\overset{+}{N}\right)}{\beta\left[K_0 + \Upsilon\left(\overset{+}{\xi}*,\overset{+}{N}\right)t\right]}.$$

The initial price of natural resources is given by:

(20) $$p(0) = \mathrm{P}\left(\overset{+}{K}_0,\overset{-}{S}_0,\overset{-}{\xi}*,\overset{-}{N}\right).$$

The rate of interest $r = \alpha Y/K$ declines over time and vanishes asymptotically. The signs of the partial derivatives given in (15)-(20) indicate the comparative statics.

Proof: By construction the solution (15)-(20) satisfies the depletion equations (1) and (1′), the capital accumulation equations (2) and the first-order conditions (5): (15) follows from solving (11) and (14); (16) follows from integrating (18); (17) comes from substituting the solutions for *s* and *Y* into (9); (18) is derived from substituting the solution for *R*(0) into (12′); (16) is obtained by integrating (18) using (1′) and making use of (13) and $R(0) = Y^{1/\beta}K_0^{-\alpha/\beta}$; (19) comes from substituting (15) and (17) into (7) and making use of (11); and (20) follows immediately from $p(0) = \beta Y / R(0) = K_0{}^{\alpha} R\left(\overset{-}{K}_0,\overset{+}{S}_0,\overset{+}{\xi}*,\overset{+}{N}\right)^{-(1-\beta)}$. We note from (17) that the transversality condition (6) on the K_i, i=1,..,N is satisfied provided $\rho = r^* > 0$. The transversality condition (6) on the resource stocks are also satisfied, since from (16) we see that $S(t)$ vanishes as $t\to\infty$. We have thus established that the hypothesized solution is an open-loop Nash equilibrium solution. To establish the comparative statics properties, we totally differentiate (11) and (14) and solve to obtain:

$$\Delta \mathrm{d}Y = \left(\frac{\alpha-\beta}{1-\beta}\right)\left(\frac{Y}{K_0}\right)\mathrm{d}K_0 + \left(\frac{\beta}{1-\beta}\right)\left(\frac{Y}{S_0}\right)\mathrm{d}S_0 + \left(\frac{\beta^2}{\alpha s(1-\beta)}\right)\mathrm{d}[\xi^*(N-1)]$$

$$\Delta \mathrm{d}s = -\left(\frac{\beta\xi^*(N-1)}{\alpha Y^2}\right)\left[\left(\frac{\alpha-\beta}{1-\beta}\right)\left(\frac{Y}{K_0}\right)\mathrm{d}K_0 + \left(\frac{\beta}{1-\beta}\right)\left(\frac{Y}{S_0}\right)\mathrm{d}S_0\right] + \left(\frac{\beta}{\alpha Y}\right)\mathrm{d}[\xi^*(N-1)],$$

where $\Delta \equiv 1+[\beta^2\xi^*(N-1)]/[\alpha sY(1-\beta)] \geq 1$. For C=(1–s)Y, sY and $R(0)=Y^{1/\beta}K_0^{-\alpha/\beta}$ we get:

$$\Delta \mathrm{d}C = \left(\frac{1-s}{1-\beta} + \frac{\beta\xi^*(N-1)}{\alpha Y(1-\beta)}\right)\left[(\alpha-\beta)\frac{\mathrm{d}K_0}{K_0} + \beta\frac{\mathrm{d}S_0}{S_0}\right] - \left[\frac{\beta(s-\beta)}{\alpha(1-\beta)}\right]\mathrm{d}[\xi^*(N-1)]$$

$$\Delta \mathrm{d}\Upsilon = \left(\frac{s}{1-\beta} - \frac{\beta\xi^*(N-1)}{\alpha Y(1-\beta)}\right)\left[(\alpha-\beta)\frac{\mathrm{d}K_0}{K_0} + \beta\frac{\mathrm{d}S_0}{S_0}\right] + \left[\frac{\beta}{\alpha(1-\beta)}\right]\mathrm{d}[\xi^*(N-1)]$$

$$\Delta \mathrm{d}R(0) = -\left\{\left(\frac{1-\alpha}{1-\beta}\right) + \left(\frac{\alpha}{\beta}\right)(\Delta-1)\right\}R(0)\left(\frac{\mathrm{d}K_0}{K_0}\right) + \left(\frac{R(0)}{1-\beta}\right)\left(\frac{\mathrm{d}S_0}{S_0}\right) + \left(\frac{\beta R(0)}{\alpha sY(1-\beta)}\right)\mathrm{d}[\xi^*(N-1)].$$

where we note from (11) that the first term in brackets on the right-hand side of the equation for $\Delta \mathrm{d}\Upsilon$ vanishes. Given that $\alpha > \beta$, the signs of the partial derivatives in (15)-(20) follow immediately from these expressions. □

We only have a meaningful solution with positive levels of aggregate consumption, output and saving/investment while natural resource reserves decline if capital is more important in production than natural resources. If $\alpha < \beta$, output cannot be sustained at a constant level with a finite stock of natural resources even if all of output is saved. Consequently, private consumption eventually vanishes.[8] We thus assume $\alpha > \beta$. The levels of aggregate consumption and output that can be sustained are then larger if the initial stock of private assets and common stock of natural reserves are higher. The initial natural resource price is low if the initial stock of natural resource reserves is high and the initial capital stock is low. Over time, natural resource prices increase. This induces continuous factor substitution, so that gradually the capital stock grows and the use of natural resources declines. Furthermore, we see from (19) that both the initial natural resource price and its rate of increase are higher while initial resource depletion is also higher in a more fractionalized society.

Armed with proposition 1, we can characterize the non-cooperative equilibrium outcome precisely. Before we discuss this in more detail, we briefly review the apolitical Hotelling and Hartwick rules and equilibrium outcomes that prevail in a society with no rival factions (i.e., with N=1). These are also the outcomes that prevail under a social planner (see Solow (1974)) or in a heterogeneous society with perfectly secure property rights ($N > 1$ and $\xi^* = 0$).

5. Benchmark: Secure Property Rights or No Rival Factions

Consider a homogenous society without any rival factions or a heterogeneous society with perfect property rights. In that case, either $N = 1$ or $\xi^* = 0$ and (11) and (14) imply that

$$(21) \qquad s = \beta, \quad Y = \left[(\alpha - \beta) S_0 K_0^{\frac{\alpha-\beta}{\beta}} \right]^{\frac{\beta}{1-\beta}} \text{ and } C = (1-\beta)\left[(\alpha - \beta) S_0 K_0^{\frac{\alpha-\beta}{\beta}} \right]^{\frac{\beta}{1-\beta}}.$$

The saving rate of a homogenous society thus equals the share of natural resources in value added β. Hence, the value of depleted natural resources is fully saved and invested (i.e., $pR = \beta Y = sY$). This is the celebrated Hartwick rule. Genuine saving is zero when there are no rival factions or property rights are perfect:

$$(22) \qquad s_G(\mathrm{t}) \equiv \frac{\dot{K}(\mathrm{t}) + p(\mathrm{t})\dot{S}(\mathrm{t})}{Y(\mathrm{t})} = \frac{\beta Y(\mathrm{t}) - p(\mathrm{t})R(\mathrm{t})}{Y(\mathrm{t})} = 0.$$

The Hartwick rule thus requires that the depletion of natural wealth is exactly compensated by accumulation of physical capital, hence genuine saving is zero. By transforming exhaustible natural resources into productive capital, the country sustains constant levels of consumption, output and investment.[9] Investment in capital is positive and compensates exactly for the loss in natural wealth.[10] The value of natural resources extracted at each point of time pR does not

[8] Natural resources are also essential if physical capital depreciates in a radioactive manner, but not if depreciation is linear or proportional to output.

[9] In a market economy without externalities constant genuine saving corresponds to constant instantaneous utility and thus constant consumption (Dixit et al. 1980). More generally, Hamilton and Withagen (2007) demonstrate that prescribing genuine saving as a constant positive fraction of output yields a path with unbounded consumption and higher wealth than the standard Hartwick rule of zero genuine saving and constant consumption.

[10] Capital grows ad infinitum while the interest rate and the depletion rate decline to zero. If positive total factor productivity growth is introduced, there may be a steady state with a positive interest rate and a positive depletion rate as discussed in Dasgupta and Heal (1974).

change over time, since the depletion level of resources falls at exactly the same rate as the price of resources appreciates. This rate is, of course, the market interest rate in a homogenous society, which declines over time and vanishes asymptotically ($\dot{p}/p = -\dot{R}/R = r$).

6. A Fractionalized Society with Insecure Property Rights

A fractionalized society saves more than the natural resource rents, so the saving rate exceeds β. The savings rate is high if there are many rival factions and less secure property rights. The upward bias in the savings rate is less if aggregate output is high or, alternatively, if the initial stocks of natural resource reserves and productive capital are high. The constant level of output is higher in more fractionalized societies with less secure property rights. Nevertheless, due to the higher savings rate, consumption is less with rival factions and imperfect property rights. The inefficient allocation in this economy arises from the lack of fully effective property rights for natural resources. Each group thus extracts resources at a too fast a pace, saves too much and consumes too little. Rapacious rent seeking thus hurts consumption by the members of each group and harms social welfare.

Since our use of the Cobb-Douglas production function implies that the demand for natural resources (i.e., $R(t) = \beta Y/p(t)$) is iso-elastic, natural resource revenues $p\ R = \beta\ Y$ stay constant all the time. As a result, natural resource wealth defined as the present value of current and future resource rents is given by:

(22)
$$\int_0^\infty p(t)R(t)\exp[-\int_0^t r(v)\mathrm{d}v]\mathrm{d}t = \beta Y \int_0^\infty \exp\left[-\int_0^t \left(\frac{\alpha Y}{K_0 + sYv}\right)\mathrm{d}v\right]\mathrm{d}t$$
$$= \beta Y \int_0^\infty \left(\frac{K_0}{K_0 + sYt}\right)^{\frac{\alpha}{s}} \mathrm{d}t = \left(\frac{\beta}{\alpha - s}\right) K_0$$

provided that $\alpha > s$. Note that the value of selling all reserves at once (i.e., $p(0)S_0$) falls short of the present value of current and future oil revenues in fractionalized societies with imperfect property rights, since using $p(0) = \beta Y / R(0) = \beta K_0{}^{\alpha} R(0)^{\beta - 1}$ and substituting $R(0)$ from (14) and then comparing with (23) we obtain

(24)
$$p(0)S_0 = \left[\frac{\beta^2}{s(\alpha - \beta)}\right] K_0 \le \int_0^\infty p(t)R(t)\exp[-\int_0^t r(v)\mathrm{d}v]\mathrm{d}t = \left(\frac{\beta}{\alpha - s}\right) K_0.$$

We thus see that in homogenous societies or in fractionalized societies with perfect property rights, the market value of the initial stock of natural resource reserves exactly equals the present value of current and future resource revenues (as then $s = \beta$ and (24) holds with equality). However, if there are competing factions and property rights on natural resources are badly defined, the savings rate is higher than predicted by the Hartwick rule ($s > \beta$) and depletion of natural resources is rapacious. This too rapid selling off of natural resource reserves is triggered by the value of resource reserves in the ground being less than the present discounted value of all current and future resource revenues.

Total wealth consists of financial capital, human wealth (i.e., the net present value of the return on the fixed factor)[11] and natural resource wealth. Human wealth is proportional to natural resource wealth and equals $(1-\alpha-\beta)K_0/(\alpha-s)$. Total initial wealth can thus be written as

$$(25) \qquad K_0 + \left(\frac{1-\alpha-\beta}{\alpha-s}\right)K_0 + \left(\frac{\beta}{\alpha-s}\right)K_0 = \left(\frac{1-s}{\alpha-s}\right)K_0 = \int_0^\infty C\exp[-\int_0^t r(v)\mathrm{d}v]\mathrm{d}t > K_0.$$

We thus see that the present discounted value of the stream of current and future sustainable consumption exactly equals total initial wealth from productive capital, labor and natural resources. Interestingly, (25) and proposition (1) indicate that fractionalization and less secure property rights boosts the savings rate and thus boost total initial wealth. Still, we know from (15) that consumption decreases if there are more rival factions and property rights become less secure. The reason is that, even though the interest rate is initially higher, it falls more rapidly in a fractionalized society and eventually becomes less than in a homogenous society. Consequently, the present value of the lower level of the stream of constant consumption levels is higher despite the lower level of sustainable consumption. Finally, despite natural resource reserves being depleted all the time, natural resource wealth, human wealth, financial wealth and thus total wealth increase throughout as the capital stock rises and the interest rate falls as time proceeds.

7. Genuine Saving in a Resource Economy with Market Failures

The economy with competing factions has an imperfect mechanism for resource allocation and thus yields an inefficient allocation with too rapid extraction and too low levels of consumption from a social point of view. One can then apply the theoretical framework for national accounting in economies with imperfect allocation mechanisms developed by Dasgupta and Mäler (2000),

[11] Human wealth can also be interpreted as the value of land, i.e, the present discounted value of land rents.

Dasgupta (2001b) and Arrow, Dasgupta and Mäler (2003) to our economy. They show that the sign of the genuine saving indicator in a model with two capital goods (not unlike the present model) depends on the accounting price of the natural resource in terms of capital. This accounting price equals the relative effect of a marginal increase in the initial stock of natural resources on the social objective function divided by the relative effect of a marginal increase in the initial capital stock on the social objective function.

In our model all groups in society have a maxi-min objective function. Since we know that the intertemporal preferences of all groups are aligned, the social objective function will be maxi-min as well. Equation (15) gives an expression for sustainable consumption $C(K_0,S_0,\xi^*,N)$, which gives an indication of social welfare. Since only the relative price matters, the numeraire for the social welfare indicator does not matter. The appropriately corrected accounting price of natural resources, $p_G(0)$, to be used in the genuine saving indicator is thus given by

(26) $$p_G(0) \equiv \frac{\partial C(K_0,S_0,N)/\partial S_0}{\partial C(K_0,S_0,N)/\partial K_0} = \left(\frac{\beta}{\alpha-\beta}\right)\frac{K_0}{S_0},$$

where the partial derivatives in the proof of proposition 1 have been used to derive (26). We define the genuine savings ratio as $s_G(0) \equiv [\dot{K}(0) + p_G(0)\dot{S}(0)]/Y(0)$ and prove that it is zero.

Proposition 2: Genuine saving is zero in fractionalized societies with insecure property rights.

Proof: We use (1) and (11) and then substitute (26) to write

$$s_G(0) = [sY(K_0,S_0,N) - p_G(0)R(0)]/Y(0) = s - \left(\frac{\beta}{\alpha-\beta}\right)\frac{K_0R(0)}{Y(0)S_0}.$$

Substituting $Y(0) = K_0^{\alpha}R(0)^{\beta}$ and $R(0)$ from (14), we obtain $s_G(0) = 0$. □

It is interesting to note that, if the true accounting price is used to value the stock of natural resource reserves, the value of reserves under the ground thus calculated exactly equals the present discounted value of current and future natural resource revenues:

(24′) $$p_G(0)S_0 = \int_0^{\infty} p(t)R(t)\exp[-\int_0^t r(v)\mathrm{d}v]\mathrm{d}t = \left(\frac{\beta}{\alpha-s}\right)K_0 \geq p(0)S_0.$$

We also note that the *accounting* price $p_G(0)$ as function of the relative stock of physical capital to natural resources for a fractionalized society with insecure property rights is exactly the same as the *market* price of natural resource in a *homogenous* society or in a society with perfectly secure property rights, that is $p(0)=\left[\frac{\beta^2}{s(\alpha-\beta)}\right]\frac{K_0}{S_0}\le p_G(0)$ and equals (26) only if $N = 1$, $\xi^* = 0$ and thus $s = \beta$ from (11). This reflects that the trajectory of physical capital and natural resource in (K,S)-space are exactly the same in the homogenous and fractionalized societies. This is why genuine saving is zero and not negative and why development in this economy with competing factions and insecure property rights on natural resources is sustainable. The problem from a social perspective is that movement along this trajectory is too fast in a fractionalized society, thus leading to an inefficiently low constant level of sustainable consumption. Hence, both the rate of depletion of natural resources and the rate of investment occur are too high and are the same, so that genuine saving will be zero while the level of sustainable consumption is too low.[12]

The World Bank (2006) calculates, however, its empirical estimate of the genuine saving indicator with the *actual* market price. Arrow, Dasgupta and Mäler (2003) stress that relying on market observables to infer social welfare can be misleading in imperfect economies. In our model the World Bank approach corresponds to using the market price $p(0)$ with $N > 1$ and $\xi^* > 0$ instead of the accounting price $p_G(0)$ (i.e., $p(0)$ with $N = 1$ or $\xi^* = 0$). Expression (24′) indicates that the correct accounting price $p_G(0)$ that should be used for the calculation of genuine saving is higher than the market price, especially if there are many competing factions and property rights are more insecure.[13] Hence, the World Bank indicator of genuine saving would in our framework show up as *positive* for a fractionalized society with imperfect property rights:

$$(22') \qquad s_G^{WB}=\frac{sY-pR}{Y}=s-\beta=\beta\left[\frac{\xi^*(N-1)}{\alpha Y}\right]>0 \ \text{ if } \ N>1 \text{ and } \xi^*>0.$$

Since the properly calculated measure of genuine saving should be zero, the World Bank estimate is thus likely to over-estimate genuine saving for countries with many rival factions.

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[12] This result is independent of the particular parameterization linking property rights to the capital stock, since the result of zero genuine saving is also obtained in a model where rival groups are tapping a common natural resource with no property rights at all (van der Ploeg, 2008).

[13] With $\alpha = 0.4$, $\beta = 0.1$ (0.3) and $N = 5$, the accounting price should be a half (quarter) of the market price.

8. Puzzle: Biases in Empirical Measures of Genuine Saving

Our game-theoretic analysis has captured some inefficiencies resulting from squabbling about natural resources in economies with fractionalization, insecure property rights and high risks of expropriation.[14] To get a better grasp of our results, consider the *genuine* saving figures reported by Hamilton and Hartwick (2005), Hamilton, Ruta and Tajibaeva (2005) and the World Bank (2006).[15] Dasgupta and Mäler (2000) show that under a social planner, genuine saving thus defined equals the increase in wealth of the nation and realizing the constant maxi-min level of consumption demands *zero* genuine saving.[16] [17] Proposition 2 shows that zero genuine saving also results in fractionalized economies with insecure property rights provided the right accounting prices are used. Any depletion of natural resources or damage done by stock pollutants must thus be compensated for by increases in non-human and/or human capital. However, equation (22′) suggests that, if societies are fractionalized with badly defined property rights as is the case for many resource-rich countries, the World Bank way of calculating genuine saving with market rather than accounting prices should yield positive figures for genuine saving.

Interestingly, the scatter diagram and estimated regression line in Figure 2 indicate that countries with a large percentage of mineral and energy rents of GNI typically have *negative* genuine saving rates as reported by the World Bank.[18] True figures of genuine saving are thus likely to be even more negative. Figures 3 gives a weak indication that countries with a share of mineral rents greater than 5 percent have more negative genuine saving rates if they have a high degree of ethnic fractionalization. Internal conflict and high levels of corruption are also associated with negative genuine saving rates in resource-rich countries.

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[14] Resource-rich countries have indeed poor growth performance after controlling for quality of institutions, openness, the investment rate and initial income per capita (e.g., Sachs and Warner, 2000).

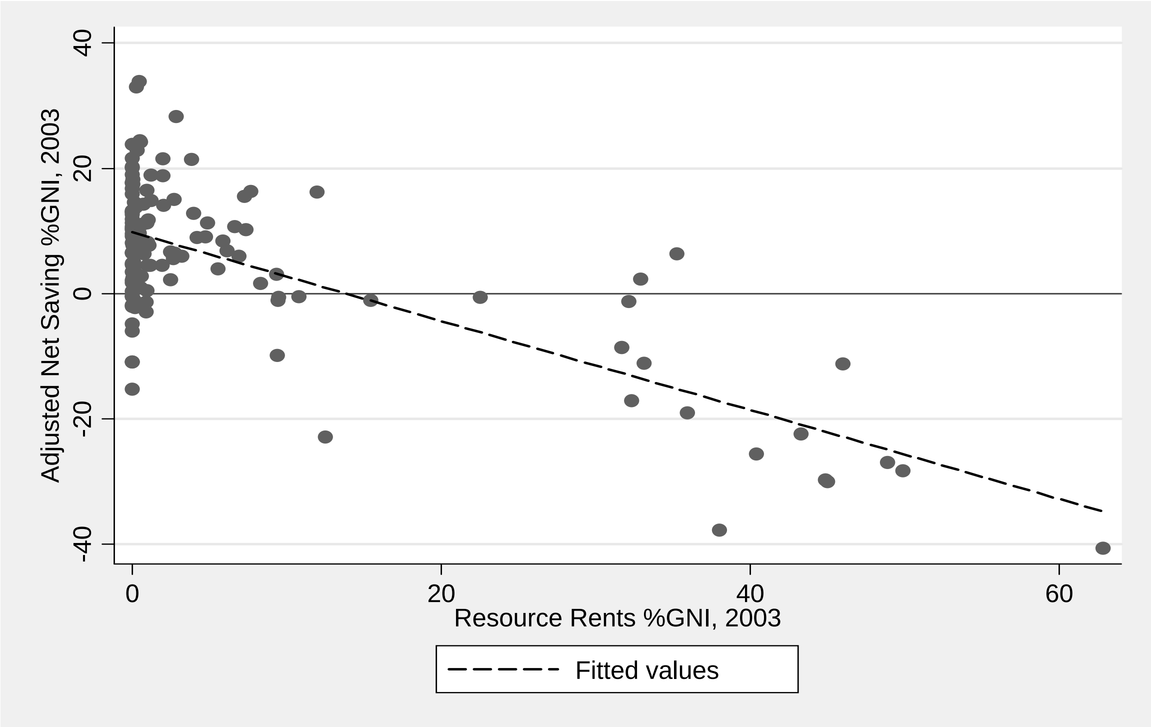
[15] Genuine saving is calculated as public and private saving at home and abroad, net of depreciation, *plus* current spending on education to capture changes in intangible human capital *minus* depletion of natural exhaustible and renewable resources *minus* damage of stock pollutants (CO_2 and particulate matter).

[16] In fact, Dasgupta (2001a) shows that wealth per capita is the correct measure of social welfare if the population growth rate is constant, per capita consumption is independent of population size, production has constant returns to scale, *and* current saving is the present value of future changes in consumption.

[17] The Hartwick rule is related to Hicksian real income. Asheim and Weitzman (2001) and Sefton and Weale (2006) show that the rule ensures no change in the present discounted value of current and future utility and requires use of the Divisia index of real consumption prices. Capital gains represent the capitalization of the future changes in factor prices and thus constitute a transfer from one factor to another. In the closed economy net gains are zero and should not be included in real income.

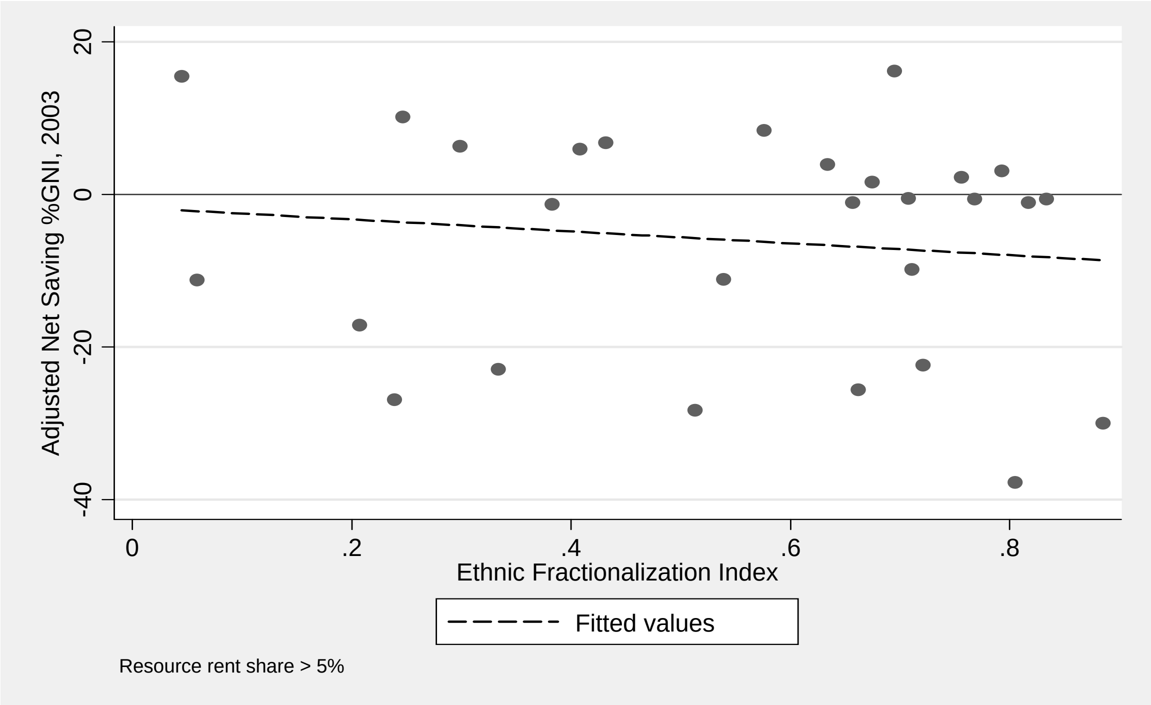
[18] The following resources are included: bauxite, copper, iron ore, lead, zinc, phosphates, silver, gold, oil, natural gas, brown coal, hard coal, tin, and nickel.

Figure 2: Genuine saving and natural resource rents



Source: World Bank (2006)

Figure 3: Genuine saving and ethnic fractionalization for resource-rich countries



Source: International Country Risk Guide and World Bank (2006)

Many countries thus become poorer each year despite have abundant natural resources. They seem to squander their natural resource wealth without investing sufficiently in other forms of intangible or productive wealth. This may explain why oil-rich Venezuela enjoyed negative economic growth while Botswana, Ghana and China with positive genuine saving rates benefit from substantial growth. Highly resource-dependent Nigeria and Angola have genuine saving rates of minus 30 percent, clearly impoverishing future generations. The oil/gas states of Azerbaijan, Kazakhstan, Uzbekistan, Turkmenistan and the Russian Federation also have negative genuine saving rates. Venezuela, Trinidad and Tobago and Gabon might have been as wealthy as South Korea if they would have reinvested their resource rents. All these countries (except Trinidad and Tobago) have suffered declines in per capita income from 1970 to 2000.

The negative genuine saving rates reported by the World Bank for resource-rich countries are cause for concern, especially as the true figures are even more negative once we allow countries having group rivalry and insecure property rights. In the real world, rapacious resource depletion goes hand in hand with insufficient rather than excessive reinvestment of resource rents. Many of the poorest resource-rich countries can thus not sustain consumption, especially if they also need to save to fight off high population growth rates and declining wealth per capita (e.g., World Bank 2006, Table 5.2). Such countries need *positive* rather than *zero* genuine saving to maintain constant consumption per head, since they are on a treadmill and need to save more than their resource rents. Unfortunately, both the corrected and uncorrected World Bank figures suggest that they rarely manage that.

Our theory of rapacious resource depletion does not explain this bias towards under-investment and negative genuine saving. One possibility is that countries save less than their natural resource rents and postpone extraction if they anticipate future world prices of resources to rise as discussed in Asheim (1986, 1996) and Vincent, Panayotou and Hartwick (1997). But Hamilton and Bolt (2004) show that the adjustments to allow for changes in future resource prices are small if historical price trends are extrapolated. If resource-rich countries expect the future cost of natural resource extraction[19] or future government spending to fall, it is also optimal to have negative genuine saving rates. An alternative explanation is that fighting about natural resources induces corruption and erosion of the legal system. This discourages saving and

[19] US historical experience suggests that under the right circumstances anticipated falls in extraction costs and thus the downward effect on the nation's saving is substantial. US supremacy as mineral producer was driven by big falls in exploration costs from the mid-nineteenth to mid-twentieth century, collective learning, leading education in mining/engineering/metallurgy, increasing returns, private initiative and an accommodating legal environment; see Habbakuk (1962) and David and Wright (1997).

investment in productive capital as in Hodler (2006). Infighting about natural resources is further exacerbated by shortsighted politicians.

9. Conclusion

What happens to national saving and investment if legal systems function badly and rival groups deplete exhaustible natural resources with imperfectly defined property rights? With perfect property rights, the country would transform its exhaustible resources into productive capital by reinvesting all resource rents (the Hartwick rule) and thus sustain constant levels of consumption and output. The rate of appreciation of the price of natural resources would equal the interest rate (the Hotelling rule), which gradually decreases over time as the capital stock grows. Resources are depleted steadily, but natural resource wealth increases throughout nevertheless. Matters are very different in a fractionalized society with insecure property rights. Although the country still manages to sustain constant levels of consumption and output, these levels are sub-optimally low. Imperfect property rights induce common-pool externalities, which drive the rate of appreciation of the price of natural resources at a too high a pace. The rapacious depletion that ensues implies that substitution of natural resources for productive capital occurs faster than is socially optimal. Hence, the savings rate is too high and extraction of natural resources too rapid compared with the social optimum. Fewer resources are thus available for consumption, especially in countries with a large degree of fractionalization and poor legal systems. People really are worse off.

Our theory predicts *zero* genuine saving rates even in fractionalized societies with imperfect property rights. The reason is that both the rate of depletion of natural resources and the rate of investment in productive capital occur too fast and at the same rate, thus genuine saving is zero yet the level of sustainable consumption is lower. Genuine saving indicators for many resource-rich countries as calculated by the World Bank are actually *negative*, and the true figures will be even more negative as true *accounting* prices (i.e., the market prices that would prevail in a society with perfect property rights) rather than the lower *market* prices should be used when calculating genuine saving. This is a real worry, especially for countries which should be saving more than their resource rents to cope with high population growth rates.

The challenge for future research is thus to offer political economy explanations of why genuine saving rates in many resource-rich economies are *negative* even though erosion of the legal system and the resulting infighting about natural resources boosts the saving and investment rate while leaving genuine saving unaffected. In practice, however, natural resource revenues may be siphoned off by the political elite and their cronies and thus not reach the people. Furthermore, natural resource bonanzas may induce exuberant, unsustainable public spending, based on the erroneous premise that windfall natural resource revenues are permanent, and painful adjustments when the windfall ceases. Also, property rights may depend not only on the aggregate capital stock, but also on whether the capital stock of one group is bigger than that of rival groups which may enable the group to better protect its natural resources but also may make rival groups more apt to steal their resources. Fighting and weapon investments by the various groups would then depend positively on the size of natural resources to be captured and negatively on the opportunity cost of labor when it is not fighting. Wasteful fighting and investment in weapons may well lead to negative genuine saving rates. Finally, politicians seek office and grab resource rents for themselves or to pay off political opponents and get away with it due to poor institutions, bad legal systems and poor checks and balances in the political system. Rapacious rent seeking implies that many resource-rich, fractionalized countries with poor legal systems squander their natural resource rents and suffer disastrous economic and social outcomes. It may even be that the extra rents that are not captured are not fully saved and invested, thus leading to negative genuine saving and impoverishment of the country.

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