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Rapacious Resource Depletion, Excessive Investment and Insecure Property Rights: A Puzzle

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RAPACIOUS RESOURCE DEPLETION, EXCESSIVE INVESTMENT AND INSECURE PROPERTY RIGHTS: A PUZZLE[1]

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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 theory suggests that power struggle boosts output but depresses aggregate consumption and welfare, especially in highly fractionalized countries with less secure property rights. Also, adjusted net saving estimates calculated by the World Bank using market prices over-estimate welfare-based measures of genuine saving. Since our theory suggests that genuine saving is zero while empirically they are negative in resource-rich, fractionalized countries, we suggest ways of resolving this puzzle.

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

Keywords: Exhaustible resources, Hotelling rule, Hartwick rule, capital, sustainable consumption, fractionalization, seepage, interconnected pools, insecure property rights, differential game, genuine saving, adjusted net saving

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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. [3] 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, because of seepage between different interconnected fields or reservoirs of natural resources.[4] Our analysis is thus concerned with non-renewable natural resources that are prone to seepage, such as oil, gas or water, and not with the whole range of exhaustible reserves to which the Hotelling rule applies. Seepage of resources between interconnected fields or reservoirs introduces a dynamic common-pool problem, especially if the rate of seepage is substantial. In the dynamic interconnected pool problem that is being studied each pool owner has legal rights to his pool of resources but nevertheless the pool owner faces non-instantaneous seepage from or to

[3] 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.

[4] 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. Fish does not respect territorial waters, but is a renewable resource.

neighboring pools. If seepage is instantaneous, it is no longer feasible to enforce property rights and our problem reduces to the familiar dynamic common pool problem.

One of our key analytical results is that competing factions extract natural resources too fast for fear of their reserves seeping to other fields and that this leads to a lower level of sustainable consumption. 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. 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.

We show that fractionalized countries substitute away from natural resources to capital in production at a too rapid rate from a social perspective so that they save and invest more than a homogenous society. We also 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. We show that the power struggle in a fractionalized society with insecure property rights leads to faster depletion of natural resources and consequently a higher saving and investment rate. This boosts output. However, due to the higher savings rate, a smaller proportion of output is devoted to consumption. This is why, despite the increase in output, fractionalization and less secure property rights depress the sustainable level of aggregate consumption and social welfare, especially if there are many rival factions and property rights are less secure.

Confronting our theory with the empirical facts, we see that oil-rich countries indeed invest a substantial proportion of their oil revenues in human and physical capital and the data are not inconsistent with their rates of oil depletion and their rates of investment being excessively high while the sustainable level of consumption is excessively low from a social point of view. The recent bursting of real-estate booms in oil-rich countries such as Kazakhstan (Kuralbayeva, van der Ploeg and Venables, 2010) and the Gulf States seems to suggest that investment rates might have been excessive and may not have been directed at productive projects.

However, there is an empirical puzzle which our theory is not yet able to address, namely that the data suggest that resource-rich countries have negative genuine saving while our theory of rapacious resource depletion suggests that genuine saving is zero even in fractionalized societies with insecure property rights if, following Arrow, Dasgupta and Mäler (2003), welfare-based accounting prices are used to value the cost of resource depletion. 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. The empirical puzzle is even more severe, since true genuine saving may be even more negative than the negative adjusted net saving estimates reported by the World Bank for many resource-rich countries, especially if they have a high degree of fractionalization and insecure property rights. The reason for this data anomaly is that the correct accounting price corresponds to the market price that prevails in a homogenous society, and is thus higher than the market price that prevails in a fractionalized society. Hence, the cost of resource depletion is under-estimated as the World Bank uses market prices instead of accounting prices so that net adjusted saving gives a too flattering indication of genuine saving.

Be that as it may, our theory does not resolve the empirical puzzle of negative genuine saving. In future work we may make progress on this if we address political economy of politicians with less extreme intergenerational equity concerns than is customary in the literature on exhaustible natural resources. It would also help to allow for absorption constraints, so that the too rapid investment cannot be immediately put to productive use and is likely to be invested in inefficient partisan, illiquid projects (e.g., Robinson and Torvik, 2005; Collier, et al., 2010). Furthermore, fighting about the share of natural resources may be wasteful in terms of foregone labor income, corruption, war, etcetera and this may help to explain the empirically observed negative genuine saving rates. The political economy of resource-rich countries (e.g., Hodler, 2006; Caselli, 2006; Caselli and Cunningham, 2009) is not concerned with the dynamics of exhaustible natural resources, but will be a source of inspiration for future theoretical work on explaining this empirical puzzle.

For example, our analysis does not deal with asymmetries as we suppose that all factions are identical with the same initial stocks of natural resources, the same level of productivity, and the same population size and abstract from the possibility that seepage may benefit some resource owners more than others. We also do not consider a ruler supported by an elite or selectorate which owns the resource, decides on its extraction and to whom the resource proceedings accrue, but focus instead on factions wrestling resource rents from each other, but not from the ruler. If there was a ruler, Caselli (2006) shows, abstracting from Hotelling features of resource depletion, that power struggles increase the effective discount rate of the governing group and that as a result this elite makes fewer investments in the long-run development of the economy. Interestingly, this goes against our result which suggests that rapacious depletion rates much lead to excessive investments. Such ruler-follower models and the importance of understanding how natural resources might impact the political survival of the ruler are also discussed in Caselli and Cunningham (2009). Most of the aforementioned asymmetries feature in the real world, but are not the focus of this paper. Instead, we focus at the Hotelling model of non-cooperative resource depletion and how this interacts with the important question of genuine saving and sustainable consumption.[5]

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. The open-loop Nash equilibrium solution has an infinite period of commitment and is relevant when different factions in society cannot monitor each others' resource stocks. With this solution the dynamic distortions arising from the common pool problem are less severe. We focus on the open-loop Nash equilibrium solution mainly because it leads to a more tractable analysis with closed-form analytical solutions. Furthermore, under this solution concept an economy with no seepage and/or perfect property rights turns out to be Pareto efficient and thus provides a useful benchmark. We thus 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 (and thus abstract from the additional efficiencies that may result from smaller periods of commitment including the zero period of commitment assumed in the feedback Nash equilibrium solution). The open-loop Nash equilibrium solution allows one to analyze how the Hartwick rule of reinvesting the Hotelling scarcity rents into various forms of productive capital is affected by moving from an assumption of common-pool open-access natural resources to an assumption of 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 within the context of a dynamic common-pool problem that an

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[5] Asymmetric Stackelberg leader-follower models of natural resource depletion with a monopolistic leader (the OPEC) and a competitive fringe have been analyzed and lead to time consistency issues and some other intricate game-theroretic issues (Groot et al., 2003).

increase in the raw return on the common asset above the return on private assets increases the extent of rent seeking, depresses saving and investment and thus curbs the rate of economic growth and makes a country worse off from a social perspective. The voracity effect thus 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 analyze, in contrast, a dynamic interconnected-pool problem with common-pool properties by extending van der Ploeg (2010a) who studies genuine saving and voracious depletion within the context of a common-pool 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 analyze a dynamic interconnected-pool problem where each group owns its own stock of natural resources and where property rights on these resources 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 max-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 adjusted net 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.[6]

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. Dasgupta (2001a, p. 287) has used such diffusion process for interconnected fields or aquifers before.[7] 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 fields of natural resources 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 neighbors have lower stock of reserves, then oil, gas or water will seep away to the neighbors' fields or aquifers. Hence, with seepage, reserves of faction i increase (decrease) if its level of reserves is lower (bigger) than that of its neighbors. This means that, due to seepage, reserves of group i increase (decrease) if group i has in the past depleted relatively more (less) of its reserves than its neighbors. Note that the diffusion process (1) is symmetric, which permits an analytically convenient solution. In practice, seepage may be asymmetric so that it is physically possible that at least some resource owners will benefit at the expense of other resource owners. Such resource owners would have differing motives and incentives; we leave the analysis of the non-cooperative Nash equilibrium solution for situations with asymmetric seepage for another

[6] 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 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.

[7] The main difference is that Dasgupta (2001a) solves a partial equilibrium problem, whereas we perform a macroeconomic general equilibrium analysis. Furthermore, he characterizes the first-order optimality conditions whereas we offer a full solution.

occasion. Finally, equation (1) underlies the dynamics of the interconnected pool problem where each pool owner has legal rights to his pool of resources but nevertheless the pool owner may face non-instantaneous seepage from or to neighboring pools (i.e., ξ strictly positive and finite). If seepage were instantaneous ($\xi \to \infty$), it is impossible to enforce property rights and the dynamic interconnected pool problem reduces to the familiar dynamic common pool problem.

The political and institutional set-up of our model consists of two parts. First, there are a finite number of competing rival factions in the economy and there is no entry of new factions or exit of existing factions (no open access). Together with the assumption of a finite and strictly positive value of ξ, this leads to a dynamic common-pool problem or, to be more precise, a problem of interconnected private pools. Second, endogeneity of property rights is introduced in a starkly reduced-form manner. We suppose that property rights improve as the economy moves along its development path. The evidence reviewed in IMF (2005) offers support for this supposition. To capture this, we set $\xi \equiv \xi^*/K$, where $\xi^* \geq 0$ indicates the given initial degree of insecurity of property rights and K is 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.[8] As property rights improve along a development path, the extent of common-pool or interconnected-pools externalities diminish.[9]

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.

[8] With very strong property rights it may be possible to claim back the value of what has seeped through to neighbours, but this is unlikely to stand up in the courts. Hence, we exclude this possibility.

[9] If property rights would not improve as the capital stock grows, resource extraction would be even more rapacious and it is not feasible to sustain a constant level of consumption.

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 that output from production is zero (strictly positive) if natural resource use in production is zero (strictly positive), that is F(K_i, L_i, 0) = 0 and F(K_i, L_i, R_i) > 0 for all R_i > 0. Natural resources are *essential* if consumption C_i along any feasible program becomes zero as stock of natural reserves run out. Natural resources are *inessential* for production if there is a feasible program along which consumption is bounded away from zero as stocks of natural resource reserves run out (i.e., $\lim_{t\to\infty} C_i(t) > 0$ as $\lim_{t} S_i(t) = 0$), so feasible consumption does not vanish 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 and an elasticity of substitution greater than unity, F(K_i, L_i, 0) > 0 holds and thus natural resources are not necessary for production. Since exhaustibility of natural resources does not pose a problem, they are trivially inessential 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. Natural resources are essential for production and the economy is doomed. 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.[10] We abstract from depreciation of capital. Each group supplies 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. In modern macroeconomic theory, agents typically maximize the following intertemporal utility function:

[10] If $\alpha < \beta$, capital does not add enough to production to compensate for the declining use of natural

(3) $U_i = \int_0^\infty \mathrm{u}(C_i)\exp(-\rho t)\mathrm{dt}, \quad \mathrm{u}(C_i) = C_i^{1-1/\theta_i}/(1-1/\theta_i) \text{ if } \theta_i \neq 1, \quad \mathrm{u}(C_i) = \ln(C_i) \text{ if } \theta_i = 1,$

where ρ indicates the pure rate of time preference employed by each group and $\theta_i \equiv -\mathrm{u}'(C_i)/C_i \mathrm{u}''(C_i) > 0$ denotes the elasticity of intertemporal substitution for group i. The coefficient of relative intertemporal inequality aversion corresponds to $1/\theta_i$ (and also corresponds to the coefficient of relative risk aversion). In our context group i chooses C_i and R_i to maximize (3) 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. In contrast to modern macroeconomic theory, the economic theory of sustainability in face of exhaustible resources supposes that agents have infinite intertemporal inequality aversion. This is the limiting case of (3) as $1/\theta_i \to \infty$ or $\theta_i \to 0$ and in the limit corresponds to maximizing the intertemporal utility function:

(3′) $$U_i = \mathrm{u}\left(\text{Arg Min}\left[C_i(t), \forall t \geq 0\right]\right),$$

which corresponds to max-min or Rawlsian preferences. The reason resource economists use (3′) rather than the more general specification (3) with $\theta_i > 0$ is that for any intertemporal problem with a positive discount rate $\rho > 0$ and a strictly positive θ_i, consumption C_i vanishes asymptotically to zero as time goes to infinity and natural resource stocks run out (Dasgupta and Heal, 1979, Chapter 10.3); also see section 4. It is hard to defend that very distant generations end up consuming nothing and therefore attention is focused at Rawlsian preferences corresponding to (3) with $\theta_i \to 0$ or equivalently to (3′) which corresponds to $\theta_i = 0$.

3. Optimality Conditions for the Dynamic Common-Pool Problem

We derive for this non-cooperative differential game an open-loop Nash equilibrium solution.[11] The resulting solution will be summarized in Proposition 1. The Hamiltonian for group i maximizing (3) subject to (1) and (2) is defined by

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resources and sustain a positive level of consumption. Resources are then essential for production.

[11] 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

(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:

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

The following transversality conditions should also be satisfied:

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

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

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

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, 2010). 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 isocondition. On the margin, each group 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. [12] 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 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 political distortions in the Hotelling rule causing too rapid extraction and too rapid increases in the price of 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) $$\frac{\dot{C}_i}{C_i} = \theta_i\left(r_i - \rho\right) \text{ if } \theta_i > 0 \text{ and } \dot{C}_i = 0 \text{ if } \theta_i = 0.$$

4. Sustaining Consumption in the Dynamic Common-Pool Problem

A well-known problem with utilitarian Benthamite utility functions and positive discounting is that the optimal program implies a time path of consumption that first rises, then declines, and vanishes asymptotically or, alternatively, declines at the outset and vanishes asymptotically (e.g., Dasgupta and Heal, 1979, Chapter 10.3). There is thus at most one peak, which is further away in the future if the discount rate is smaller. An outcome where generations in the distant future consume almost nothing is hard to defend from an ethical and political point view. Hence, the exhaustible resource literature often focuses attention at max-min egalitarian outcomes, where all future generations are treated equally and enjoy the same level of consumption. This is the

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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.

[12] 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 $j \neq i$.

approach we will adopt as well and we therefore assume zero elasticities of intertemporal substitution (i.e., $\theta_i = 0$), which correspond to a Rawlsian social welfare function.[13]

We therefore look for dynamic general equilibrium paths with constant levels of consumption, $C_i(t) = C/N > 0$, $\forall t \geq 0$ 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) $$K_i(t) = s\, Y_i(t)\, t + K_{i0} > 0,\ \forall t \geq 0,$$

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 $Y_i(t) = sY_i(t) + C/N$ 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 of each group as a diminishing function of aggregate output:

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

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

[13] An alternative is to rethink the axiomatic foundation of intertemporal preferences from an ethical point of view. One suggestion is the framework of sustainable discounted utilitarianism which imposes the requirement that the evaluation is insensitive to the interests of the present generation if the present is better off than the future generation (Asheim and Mitra, 2009).

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

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

(12′) $$R(t) = R(0) - \left[K_0^{-\alpha/\beta} - \left(K_0 + sYt\right)^{-\alpha/\beta}\right]Y^{1/\beta} = \left(K_0 + sYt\right)^{-\alpha/\beta} Y^{1/\beta},$$

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 the aggregate version of (12′), $\int_0^\infty R(t)dt = S_0$, this implies that

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

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:

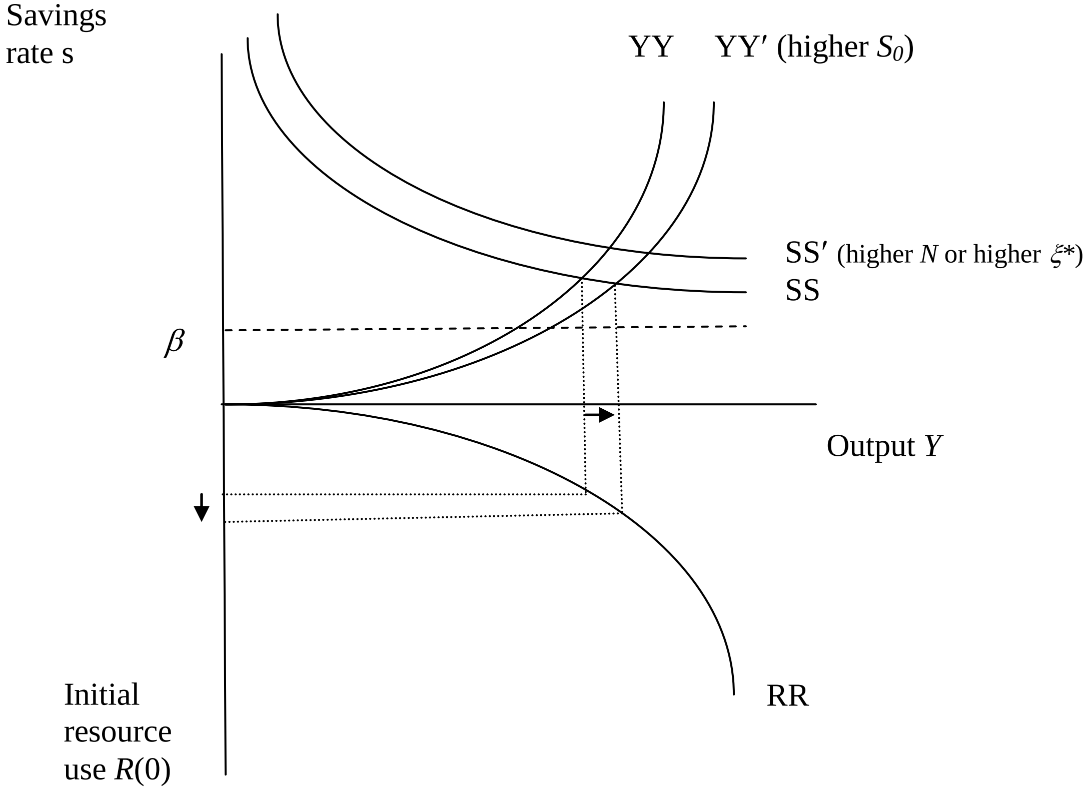
(14) $$Y = \left[s\left(\frac{\alpha - \beta}{\beta}\right) K_0^{\frac{\alpha-\beta}{\beta}} S_0\right]^{\frac{\beta}{1-\beta}} \quad \text{and} \quad R(0) = \left[s\left(\frac{\alpha - \beta}{\beta}\right) K_0^{-(1-\alpha)} S_0\right]^{\frac{1}{1-\beta}}.$$

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.

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.

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.

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:

$$(15) \qquad s = \mathrm{s}\left(\overset{-}{K_0}, \overset{-}{S_0}, \overset{+}{\xi^*}, \overset{+}{N}\right), \quad Y = \mathrm{Y}\left(\overset{+}{K_0}, \overset{+}{S_0}, \overset{+}{\xi^*}, \overset{+}{N}\right) \text{ and } C = \mathrm{C}\left(\overset{+}{K_0}, \overset{+}{S_0}, \overset{-}{\xi^*}, \overset{-}{N}\right).$$

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,

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

and a linearly increasing trajectory of the aggregate capital stock

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

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

$$(18) \quad R(t) = \left[K_0 + \Upsilon\left(\overset{+}{\xi^*}, \overset{+}{N}\right) t \right]^{-\left(\frac{\alpha}{\beta}\right)} \mathrm{Y}\left(\overset{+}{K_0}, \overset{+}{S_0}, \overset{+}{\xi^*}, \overset{+}{N}\right)^{\frac{1}{\beta}} \text{ with } R(0) = \mathrm{R}\left(\overset{-}{K_0}, \overset{+}{S_0}, \overset{+}{\xi^*}, \overset{+}{N}\right).$$

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 $\xi^* (N-1)$ is large, but this wedge vanishes asymptotically:

(19)
$$p(t)=\beta\Upsilon\left(\overset{+}{K_0},\overset{+}{S_0},\overset{+}{\xi}*,\overset{+}{N}\right)^{1-1/\beta}\left[K_0+\Upsilon\left(\overset{+}{\xi}*,\overset{+}{N}\right)t\right]^{\alpha/\beta}\quad\text{and}$$
$$\frac{\dot{p}(t)}{p(t)}=r(t)+\frac{\xi*(N-1)}{K(t)}=\frac{\alpha\Upsilon\left(\overset{+}{\xi}*,\overset{+}{N}\right)}{\beta\left[K_0+\Upsilon\left(\overset{+}{\xi}*,\overset{+}{N}\right)t\right]}.$$

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:

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

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:

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

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

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

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.[14] 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

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

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

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

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.[15] Investment in capital is positive and compensates exactly for the loss in natural wealth.[16] The value of natural resources extracted at each point of time pR does not 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 with insecure property rights 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

15 In a competitive 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.

rights.[17] 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. It can thus be seen from equations (16) and (18) that in a fractionalized society with insecure property rights each group thus extracts natural resources at a too fast a pace,

$$(23)\qquad \dot{S}(t)/S(t) = -R(t)/S(t) = \mathrm{Y}\left(\overset{+}{K}_0, \overset{+}{S}_0, \overset{+}{\xi}*, \overset{+}{N}\right)^{\frac{1}{\beta}} / S_0 > \mathrm{Y}\left(\overset{+}{K}_0, \overset{+}{S}_0, \overset{0}{\xi}*, \overset{+}{1}\right)^{\frac{1}{\beta}} / S_0,$$

and hence saves and invests 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 and are higher if the number of rival factions is higher. The interest rate is initially higher and then falls more rapidly in a fractionalized society. As a result, natural resource wealth defined as the present value of current and future resource rents is given by:

$$(24)\qquad \begin{aligned} \int_0^\infty p(t)R(t)\exp[-\int_0^t r(v)\mathrm{d}v]\mathrm{d}t &= \beta Y \int_0^\infty \exp\left[-\int_0^t \left(\frac{\alpha Y}{K_0 + sYv}\right)\mathrm{d}v\right]\mathrm{d}t \\ &= \beta Y \int_0^\infty \left(\frac{K_0}{K_0 + sYt}\right)^{\frac{\alpha}{s}} \mathrm{d}t = \left(\frac{\beta}{\alpha - s}\right) K_0 \end{aligned}$$

provided that $\alpha > s$. Natural resource wealth is higher if the number of rival factions is higher and property rights are less secure (as then s is higher). 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

[16] 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).

[17] It may seem odd that theory predicts that output is higher in fractionalized resource-rich societies with insecure property rights, because many of those economies have bad economic performance and are poor. However, those economies often also suffer from bad institutions, macroeconomic mismanagement, and high volatility of export commodity prices which tend to worsen economic performance (Poelhekke and van der Ploeg, 2009).

$p(0) = \beta Y / R(0) = \beta K_0{}^{\alpha} R(0)^{\beta-1}$ and substituting $R(0)$ from (14) and then comparing with (24) we obtain

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

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 (25) 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 as indicated by (23). 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)[18] 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

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

It thus follows that resource wealth, human wealth, and total wealth are all higher in a fractionalized society with insecure property rights (and thus a too high value of s from a social optimum perspective). Hence, the present discounted value of the stream of current and future sustainable consumption which exactly equals total initial wealth must be lower in such a society as well. Interestingly, (26) 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 the propensity to consume out of initial total wealth,

(26′) $$\frac{C(t)}{\left(\frac{1-s}{\alpha-s}\right)K_0} \equiv \Theta = \frac{1}{\int_0^{\infty}\exp[-\int_0^t r(v)\mathrm{d}v]\mathrm{d}t} = (\alpha-s)s^{\frac{\beta}{1-\beta}}\left[\left(\frac{\alpha-\beta}{\beta}\right)S_0\right]^{\frac{\beta}{1-\beta}} K_0^{\frac{\alpha-1}{1-\beta}},$$

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

is lower in a fractionalized society with insecure property rights.[19] In fact, this more than offsets the higher total initial wealth. Hence, consumption is lower despite higher initial total wealth. The intuition is as follows. 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 Resource-Rich Economies 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), 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 Rawlsian max-min objective function (3′). Since we know that the intertemporal preferences of all groups are aligned, the social objective function will be max-min as well. Equation (15) gives an expression for sustainable consumption $C(K_0, S_0, \xi^*, N)$, which indicates 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 calculating genuine saving is thus given by

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

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[19] Note that $\frac{\partial \Theta}{\partial s} = (\alpha\beta - s)\left(\frac{\alpha - s}{s(1-\beta)}\right) s^{\frac{\beta}{1-\beta}} \left[\left(\frac{\alpha-\beta}{\beta}\right) S_0\right]^{\frac{\beta}{1-\beta}} K_0^{\frac{\alpha-1}{1-\beta}} < 0$ as $s > \beta > \alpha\beta$. Since s is higher in a fractionalize society with insecurity property rights, it follows that Θ must be lower in such a society.

where the partial derivatives in the proof of proposition 1 have been used to derive (27). Following Arrow, Dasgupta and Mäler (2003), 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 (27) to write

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

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 welfare-based 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,

$$(25') \qquad p_G(0)S_0 = \int_0^{\infty} p(t)R(t)\exp[-\int_0^t r(v)\mathrm{d}v]\mathrm{d}t = \left(\frac{\beta}{\alpha - s}\right)K_0 \geq p(0)S_0,$$

whereas (25) indicates that the market values of reserves falls short of that. 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 $p(0) = \left[\frac{\beta^2}{s(\alpha - \beta)}\right]\frac{K_0}{S_0} \leq p_G(0)$ and equals (27) 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.[20]

The World Bank (2006) calculates, however, its empirical estimate of 'genuine saving' with the *actual* market price, hence it is now more appropriately called 'adjusted net saving'. Arrow, Dasgupta and Mäler (2003) stress that relying on market observables to infer social welfare can be misleading in imperfect economies. Expression (25′) implies that, if the World Bank uses the market price $p(0)$ with $N > 1$ and $\xi^* > 0$ instead of the welfare-based accounting price $p_G(0)$ (i.e., $p(0)$ with $N = 1$ or $\xi^* = 0$), it would use too low prices as the accounting price $p_G(0)$ that should be used for calculating genuine saving is higher than the market price $p(0)$, especially if there are many competing factions and property rights are more insecure.[21] Hence, the World Bank estimates of adjusted net 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 Proposition 2 states that the welfare-based measure of genuine saving should be zero, our theory suggests that the World Bank estimates of adjusted net saving over-estimate genuine saving for countries with many rival factions and insecure property rights.

8. Puzzle: Biases in Empirical Measures of Genuine Saving

So how far do our theoretical predictions of (i) low levels of sustainable consumption, (ii) excessive depletion rates due to squabbling about the appropriation of natural resources, (iii) excessive investment rates, and (iv) zero genuine saving rates, especially in fractionalized resource-rich economies with poor legal systems, stand up to the stylized empirical facts? As far as (i) is concerned, there is plenty of evidence that resource-rich countries show poor growth performance after controlling for quality of institutions, openness, the investment rate and initial income per capita (Sachs and Warner, 2000; van der Ploeg, 2010b). There is also plenty of evidence that resource-rich countries suffer from rapacious resource depletion and conflict (e.g.,

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[20] 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, 2010).

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

Lane and Tornell, 1996; Collier and Hoeffler, 2004; van der Ploeg, 2010b), which is not inconsistent with rapacious resource depletion predicted by (ii). The weak correlation reported in figure 2 is not inconsistent with hypothesis (iii) that investment rates are higher in resource-rich economies that are more fractionalized and have less secure property rights. Much of this investment may not only be excessive but also of bad quality. For example, politicians may have incentives to invest too much in partisan poor-quality projects ('white elephants') to prevent potential rivals spending the resource revenues once they get booted out of office (e.g., Robinson and Torvik, 2005; Collier, et al., 2010).

Our main concern is, however, that prediction (iv) of zero genuine saving rates, especially in fractionalized resource-rich economies, is flatly rejected by the data. Dasgupta and Mäler (2000) show that under a social planner, genuine saving equals the increase in wealth of the nation and that realizing the constant max-min level of consumption demands *zero* genuine saving.[22] [23] Proposition 2 shows that zero genuine saving also results in fractionalized economies with insecure property rights provided the welfare-based accounting prices are used, which leads to our hypothesis (iv). 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.

Correctly measured *genuine saving* data are unfortunately not available. However, *adjusted net saving* data are available and we know from equation (22′) in section 7 that these data over-estimate correctly measured genuine saving. With this caveat in mind, consider the adjusted net saving figures reported by Hamilton and Hartwick (2005), Hamilton, Ruta and Tajibaeva (2005) and the World Bank (2006).[24] [25] Looking at the estimates of adjusted net savings calculated by the World Bank for the year 2006, restricting attention to natural resources that are prone to seepage, namely oil and gas, and leaving out other resources which are not prone to seepage (minerals, coal, forestry, etc.), the scatter diagram and estimated regression line in figure 3 indicate that countries with a large percentage of oil and gas rents of GNI typically have

[22] 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.
[23] 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.
[24] Adjusted net 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).

negative adjusted net saving rates.[26] Many countries thus become poorer each year despite having abundant natural resources. They 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 adjusted net saving rates benefit from substantial growth. Highly resource-dependent Nigeria and Angola have adjusted net saving rates of minus 30 percent, thus impoverishing future generations. The oil/gas states of Azerbaijan, Kazakhstan, Uzbekistan, Turkmenistan and the Russian Federation also have negative adjusted net 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.

Section 7 states that true figures of genuine saving are likely to be more negative in fractionalized societies with poor property rights, hence making it even more likely that prediction (iv) is rejected by the data. Indeed, figure 4 suggests that countries with a share of oil & gas rents greater than 20 percent have more negative adjusted net saving rates if they have a high degree of ethnic fractionalization. Internal conflict and high levels of corruption are also associated with negative adjusted net saving rates in resource-rich countries.

The negative adjusted net 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 often goes hand in hand with excessive reinvestment of resource rents, possibly of a poor quality. 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, adjusted net saving World Bank estimates suggest that they rarely manage that.

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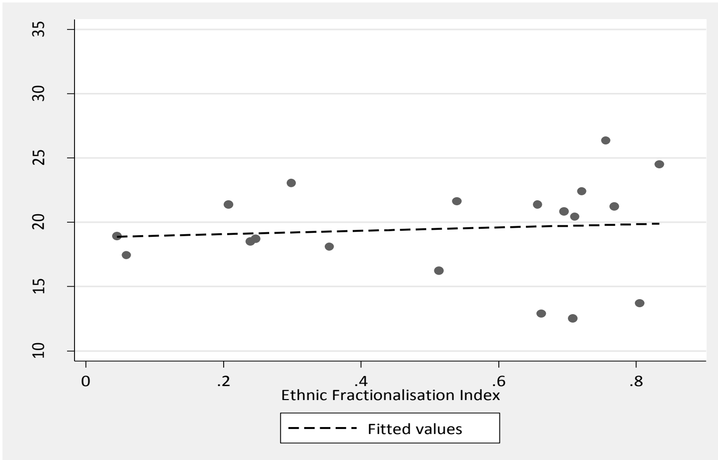
[25] These measures are increasingly used in empirical work on the natural resource curse (e.g., Ding and Field, 2005; Brunnschweiler and Bulte, 2008; Alexeev and Conrad, 2009), so it is important to understand what these figures refer to.

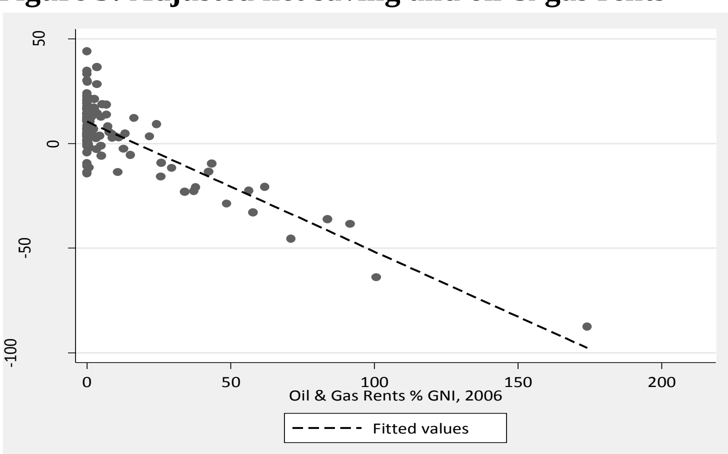
[26] The stylized facts look qualitatively the same when we use 2003 data or when we include a broader measure of natural resources consisting of bauxite, copper, iron ore, lead, zinc, phosphates, silver, gold, brown coal, hard coal, tin, and nickel as well.

Figure 2: Gross investment and ethnic fractionalization in resource-rich countries



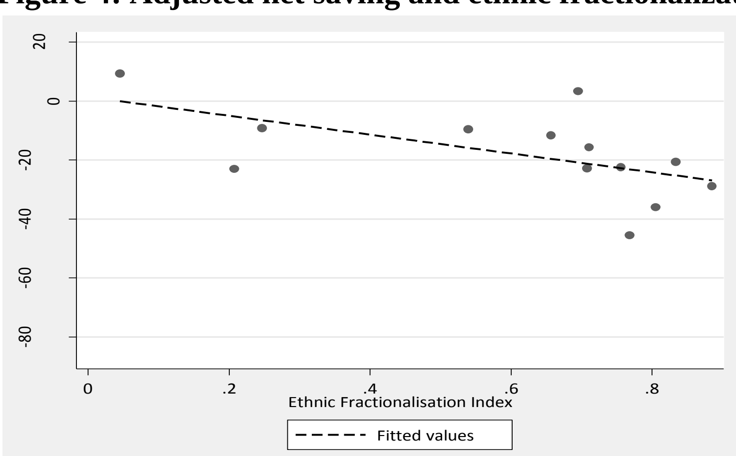
Source: International Country Risk Guide and World Bank Development Indicators

Figure 3: Adjusted net saving and oil & gas rents



Source: World Development Indicators

Figure 4: Adjusted net saving and ethnic fractionalization in resource-rich countries



Source: International Country Risk Guide and World Bank Development Indicators

Although our predictions (i), (ii) and (iii) about poor economic performance, rapacious resource depletion and excessive investment have some empirical relevance, the above discussion indicates that prediction (iv) is at variance with the stylized fact of negative genuine saving. The puzzle of explaining negative genuine saving is thus still a challenge for further research. 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[27] or future government spending to fall, it is also optimal to have negative genuine saving rates. An alternative explanation of negative genuine saving might be that fighting about natural resources implies foregone labor income and induces corruption and erosion of the legal system. This implies waste and discourages saving and investment in productive capital as in Hodler (2006). Infighting about natural resources is further exacerbated by shortsighted politicians who are less concerned with the extreme intergenerational equity concerns implied by the assumption of Rawlsian preferences customary in the literature on exhaustible natural resources. The existing literature on the political economy of resource-rich countries highlights the role of rulers and their incentives (e.g., Caselli, 2006; Caselli and Cunningham, 2009) and the role of absorption constraints and excessive investment in partisan illiquid investment projects (e.g., Robinson and Torvik, 2005; Collier, et al., 2010), which will give useful hints in the quest for a theory that might explain the puzzle of negative genuine saving.

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

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[27] 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).

very different in fractionalized societies 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 is driven by the value of resource reserves in the ground being less than the present discounted value of current and future resource revenues. Substitution of natural resources for productive capital thus occurs too fast, the saving and investment rates are too high, and extraction of natural resources too rapid compared with the social optimum. Both the rate of depletion of natural resources and the rate of investment in productive capital occur too fast and at the same rate, hence genuine saving is zero. Despite resource wealth, human wealth and total wealth being higher, sustainable consumption is lower. The reason is that the propensity to consume out of total wealth is sufficiently lower to offset the higher total wealth. People really are worse off in terms of having to make to do with a lower level of sustainable consumption, especially in countries with a large degree of fractionalization and poor legal systems.

Our theoretical predictions of poor economic performance, rapacious resource depletion and excessive investment have some empirical relevance, but our prediction of *zero* genuine saving rates is rejected by the data. Indeed, adjusted net saving indicators for many resource-rich countries as calculated by the World Bank are *negative,* and the true genuine saving 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 empirically observed negative genuine saving rates are a puzzle, since our theory did take account of erosion of the legal system and infighting about natural resources.

To explain this puzzle, one needs to introduce political economy features that can explain why natural resource revenues are not fully or not efficiently re-invested in the economy. For example, natural resource revenues may be siphoned off by short-sighted political elites and their cronies who less concerned about intergenerational equity and thus resource revenues will 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 or partisan, illiquid projects 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.

References

Alexeev, M. and R. Conrad, The elusive curse of oil, Review of Economics and Statistics 91 (2009) 3, 586-598.

Arrow, K.J., P. Dasgupta and K.-G. Mäler, Evaluating projects and assessing sustainable development in imperfect economies, Environmental and Resource Economics 26, 4 (2003) 647-685.

Asheim, G.B., Hartwick’s rule in open economies, Canadian Journal of Economics 19 (1986) 395-402.

Asheim, G.B., Capital gains and net national product in open economies, Journal of Public Economics 59 (1996) 419-434.

Asheim, G.B. and M.L. Weitzman, Does NNP growth indicate welfare improvement, Economics Letters 73, 2 (2001) 233-239.

Asheim, G.B. and T. Mitra (2009). Sustainability and discounted utilitarianism in models of economic growth, Mathematical Social Sciences, forthcoming.

Brander, J.A. and M.S. Taylor (1997). International trade and open-access renewable resources: The small open economy case, Canadian Journal of Economics, 30, 3, 526-552.

Brander, J.A. and M.S. Taylor, Open access renewable resources: Trade and trade policy in a two-country model, Journal of International Economics 44 (1998) 181-209.

Brunnschweiler, C. and E. Bulte, The resource curse revisited and revised: a tale of paradoxes and red herrings, Journal of Environmental Economics and Management 55 (2008) 3, 248-264.

Caselli, F., Power struggles and the natural resource curse, mimeo., London School of Economics (2006).

Caselli, F. and T. Cunnigham, Leader behaviour and the natural resource curse, Oxford Economic Papers, 61 (2009) 4, 628-650.

Collier, P. and A. Hoeffler, Greed and grievance in civil war, Oxford Economic Papers 56 (2004) 4, 563-595.

Collier, P., F. van der Ploeg, M. Spence and A.J. Venables, Managing resource revenues in developing economies, IMF Staff Papers, 57 (2010) 1, 84-118.

Dasgupta, P., Human Well-Being and the Natural Environment (Oxford: Oxford University Press, 2001a).

Dasgupta, P., Valuing objects and evaluating policies in imperfect economies, Economic Journal 111, Supplement (2001b) C1-C29.

Dasgupta, P. and G.M. Heal, The optimal depletion of exhaustible resources, Review of Economic Studies, Symposium (1974) 3-28.

Dasgupta, P. and K.-G. Mäler, Net national product, wealth, and social well-being, Environment and Development Economics 5 (2000) 69-93.

Dasgupta, P.S. and T. Mitra, Intergenerational equity and efficient allocation of exhaustible resources, International Economic Review 24 (1983) 133-153.

David, P.A. and G. Wright, Increasing returns and the genesis of American resource abundance, Industrial and Corporate Change 6 (1997) 203-245.

Ding, N. and B.C. Field, Natural resource abundance and economic growth, Land Economics 81 (2005) 3, 496-502.

Dixit, A.P., P. Hammond and M. Hoel, On Hartwick's rule for regular maximin path of capital accumulation, Review of Economic Studies 47 (1980) 551-556.

Groot, F., C. Withagen and A. de Zeeuw (2003). Strong time-consistency in the cartel-versus-fringe model, Journal of Economic Dynamics and Control, 28, 2, 287-306.

Habbakuk, H.J. , American and British Technology in the Nineteenth Century (Cambridge, U.K.: Cambridge University Press, 1962).

Hamilton, K. and K. Bolt, Resource price trends and development prospects, Portuguese Economic Review 3 (2004) 85-97.

Hamilton, K. and J.M. Hartwick, Investing exhaustible resource rents and the path of consumption, Canadian Journal of Economics 38, 2 (2005) 615-621.

Hamilton, K., G. Ruta and L. Tajibaeva, Capital accumulation and resource depletion: A Hartwick rule counterfactual, Policy Research Working Paper 3480, World Bank, Washington, D.C., 2005.

Hamilton, K. and C. Withagen, Savings growth and the path of utility, Canadian Journal of Economics 40, 2 (2007) 703-713.

Hartwick, J.M., Intergenerational equity and the investing of rents from exhaustible resources, American Economic Review 67, 5 (1977) 972-974.

Hodler, R., The curse of natural resources in fractionalized countries, European Economic Review 50 (2006) 1367-1386.

Hotelling, H., The economics of exhaustible resources, Journal of Political Economy 39 (1931) 137-175.

IMF, Chapter III, Building institutions, World Economic Outlook (Washington, D.C.: International Monetary Fund, 2005).

Karp, L.S., Social welfare in a common property oligopoly, International Economic Review 33 (1992) 353-372.

Kuralbayeva, K., F. van der Ploeg and A.J. Venables, Management of resource revenues in the CAREC region: the many faces of the natural resource curse, Oxcarre Policy Paper 6, University of Oxford, prepared for the Asian Development Bank (2010).

Lane, P.R. and A. Tornell, Power, growth and the voracity effect, Journal of Economic Growth 1, 2 (1996) 213-241.

Ploeg, F. van der, Inefficiency of credible strategies in oligopolistic resource markets with uncertainty, Journal of Economic Dynamics and Control, 11 (1987) 123-145.

Ploeg, F. van der, Voracious transformation of a common natural resource into productive capital, International Economic Review, 51 (2010a) 2, 365-381.

Ploeg, F. van der, Natural resources: curse or blessing?, Journal of Economic Literature, to appear (2010b).

Ploeg, F. van der and S. Poelhekke, Volatility and the natural resource curse, Oxford Economic Papers 61 (2009) 4, 727-760.

Reinganum, J.F. and N.L. Stokey, Oligopoly extraction of a common property natural resource: The importance of the period of commitment in dynamic games, International Economic Review 26 (1985) 1, 161-173.

Robinson, J.A. and R. Torvik, White elephants, Journal of Public Economics 89 (2005) 2-3, 197-210.

Sachs, J., Common Wealth. Economics for a Crowded Planet (London: Allen Lane, 2008).

Sachs, J.D. and A.M. Warner, Natural resource abundance and economic growth, in G. Meier and J. Rauch, eds., Leading Issues in Economic Development (Oxford: Oxford University Press, 2000).

Sefton, J.A. and M.R. Weale, The concept of income in a general equilibrium, Review of Economic Studies 73 (2006) 219-249.

Solow, R.M., Intergenerational equity and exhaustible resources, Review of Economic Studies Symposium (1974) 29-45.

Tornell, A. and P.R. Lane, The voracity effect, American Economic Review 89, 1 (1999) 22-46.

Vincent, J.R., Th. Panayotou and J.M. Hartwick, Resource depletion and sustainability in small open economies, Journal of Environmental Economics and Management 33 (1997) 274-286.

World Bank, Where is the Wealth of Nations? Measuring Capital for the 21st Century (Washington, D.C.: International Bank for Reconstruction and Development/World Bank, 2006).