Ownership Risk, Investment, and the Use of Natural Resources

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Abstract

The effect of insecure ownership on ordinary investment and on the exploitation of natural resources is examined. Insecure ownership is characterized as a positive probability that a typical asset or its future return will be confiscated. For empirical analysis, the probability of confiscation is modeled as a function of observable political attributes of countries, principally the type of government regime in power (democratic versus non-democratic) and the prevalence of political violence or instability. A general index of ownership security is estimated from the political determinants of economy wide investment rates, and then introduced into models of petroleum and forest use. Ownership risk is found to have a significant, and quantitatively important effect. Empirically, increases in ownership risk are associated with reductions in forest cover and with slower rates of petroleum exploration. Contrary to conventional wisdom, greater ownership risk tends to slow rates of petroleum extraction, apparently because the extraction process is capital intensive.

Key Words: ownership security, investment, resource conservation

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1. INTRODUCTION

Statistical comparisons and casual empiricism indicate that the way a country uses its environment and natural resources varies systematically with its level of development.[1] While there is some debate over what drives such relationships,[2] two separate streams of literature, one on property rights and natural resource use and the other on the sources of economic growth, seem to offer an attractive explanation. The natural resource literature points out that countries with incomplete property rights are likely to use resource stocks relatively heavily due to free access problems.[3] The economic growth literature points out that weak ownership forestalls the physical and human capital investments needed for economic development.[4] Combining the two suggests that excessive use of natural resources and low levels of economic development might be two manifestations of a single phenomenon, weak property rights.

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[1] The form of this variation and the reasons for it are subjects of a growing literature, including recent empirical research on 'environmental Kuznets curves,' relationships between a country's income and its propensity to use up or degrade its environmental and natural resources. See, for example, Grossman and Krueger (1993), World Bank (1992), Cropper and Griffiths (1994), and Seldon and Song (1994). Recent theoretical and empirical research on the effects of trade on environmental outcomes is also relevant here.

[2] Policy discussions sometimes regard it as a simple income effect, e.g., the World Bank (1992, p. 1) regards alleviating poverty as "essential for environmental stewardship."

[3] See Lopez (1994). Chichilnisky (1994) argues that incomplete property rights can create a basis for trade, causing countries with weak institutions of ownership to specialize in production of commodities that use unowned resources intensively.

[4] See Kormendi and Meguire (1985), Grier and Tullock (1989), Barro (1991), Persson and Tabellini (1994), and Levine and Renelt (1992).

While this argument has intuitive appeal there are two reasons to be skeptical. First, formal empirical evidence on how natural resource use responds to insecure ownership is very scarce. There are endless anecdotes and theoretical treatments, but little statistical evidence has been presented on the size of the relevant elasticities.[5] Second, the change in resource use that accompanies development seems to vary from resource to resource in ways that existing discussions do not capture.[6] There is much publicity about the way poorer nations, the 'South,' strip biomass from forests to obtain wood for fuel and nutrients for farming, causing the destruction of natural forest habitats. For fossil fuels and minerals, however, extraction and consumption appear more rapid and extensive in the prosperous 'North.'

There are really two questions here. First, how important, quantitatively, is insecure ownership to the use of natural resources? Second, given that insecure ownership also affects ordinary investment and economic growth, what is the implied relationship between natural resource use and levels of economic development? We focus on the first question, but also shed light on the second. To do so, we develop a general theory of investment and resource use under ownership risk, and then test it with appropriate data.

Our model implies that differences in the capital intensity of resource extraction can cause the effect of ownership risk to be qualitatively different for different resources. For resources that can be drawn down and consumed using only ordinary labor, our model predicts that stocks will be relatively low in countries with weak property rights. This occurs because the resource stock is a form of capital and drawing it down for consumption is equivalent to disinvestment. Disinvestment is likely when property rights are insecure because the risk of confiscation causes the future return from maintaining the stock to be discounted heavily. Clearing forests to obtain or fuel or agricultural land is a labor intensive extraction process that

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[5] Some evidence is emerging, however; see Alston, Libecap and Schneider (1996), Deacon (1994), Lopez (1992), and Southgate, Sierra, and Brown (1991).

[6] Lopez (1994) gives a theoretical treatment. World Resources Institute (1994, Chapter 1) cites evidence.

exemplifies this possibility. When ownership is insecure we expect trees to be cut at an earlier age and the acreage replanted following harvest to be reduced. In other words, low forest stocks and weak property rights should accompany one another.

Extraction of other resources requires a large up-front expenditure or heavy use of produced capital, however, and this can cause the opposite outcome. If ownership in a given country is insecure, these capital intensive resource stocks may remain unused because agents in the economy will not invest in the produced capital needed to exploit them.[7] Petroleum is a prime example; it requires a large outlay for exploration and production equipment before any extraction can begin.

The nature of the relationship between resource use and ownership risk is, therefore, essentially empirical. To study it we start by developing an index of ownership risk using an approach suggested by recent work on cross country variations in investment and growth. Basically, we postulate that ownership risk is related to observable political attributes of countries and then use data on economy-wide investment rates and political characteristics to estimate the form of this relationship. The result is an ownership risk index, formed by combining the political variables that affect investment with their estimated coefficients. This index is then incorporated in models of resource use for petroleum and forests to see if, and to what degree, ownership security matters.[8]

In general, we find highly significant and plausible relationships between political attributes of countries and their economy-wide investment rates, even after controlling for

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[7] Given our model of ownership risk this is equivalent to a point first made by Farzin (1985), that a higher discount rate can slow resource extraction if the extraction process is sufficiently capital intensive.

[8] Our reasons for basing the index on economy-wide investment data are as follows. First, we use the Summers and Heston (1991) series on investment, which is both widely used and far more extensive than available data sets for natural resource stocks. Second, this approach allows us to decide on an appropriate specification and set of political attributes for the risk index before examining the resource stock data that are our primary interest. Finally, in the context of standard growth models, greater ownership risk will unambiguously reduce investment in produced capital; as we show later, the effect of ownership risk on resource stocks is qualitatively ambiguous.

economic factors that modern growth theory suggests should be included. Regarding the paper's central objective, the political risk index turns out to be a highly significant and quantitatively important determinant of petroleum exploration, petroleum production, and changes in forest stocks. Contrary to conventional wisdom, we find that greater ownership risk can lead to slower exploitation of some resources.

These results are important for policy because they indicate that institutional change is a key ingredient for altering natural resource and environmental outcomes in developing countries. The results also cast doubt on the wisdom of recommendations for North to South income transfers as a means of changing the South's use of environmental and natural resources, as suggested by the World Bank (1992, pp. 1-3). Changing income alone, without accompanying policies to solidify institutions of ownership, may have little effect. Our results also imply that more secure ownership should cause heavier exploitation of some resources and lighter exploitation of others. For policy makers concerned with the global environmental implications of resource use, e.g., carbon emissions from both deforestation and fossil fuel combustion, reduced ownership risk in the Third World represents a mixed blessing.

The paper is organized as follows. Section 2 develops an economic model of investment and resource use that highlights the relationship between political risk and investment decisions. Section 3 presents the empirical analysis and section 4 concludes.

2. THEORY

To motivate later empirical analysis, this section of the paper models investments in produced capital, petroleum, and forests in an environment with ownership risk.

2.1 Investment and Ownership Risk

Ownership risk is modeled by a probability of expropriation π_t. We use the term 'expropriation' to mean any event that abridges an investor's claim to the earnings of an investment project. This includes acts of government, such as actual expropriation, capital levies, and unexpected export or excise taxes. It also includes theft by private parties and actions by capricious or ineffective courts.

In modeling the link between ownership risk and the behavior of a representative investor, we treat expropriation as an all-or-nothing event. With probability π_t expropriation occurs, which means that the investor looses all claims to investment projects at the start of period t+1. With probability $1-\pi_t$ the investor's claims remain intact.[9] For all investment decisions, we consider a small open economy that faces an exogenous world interest rate $r>0$. If the investor discounts future income at rate r and expects to lose his or her investment with probability π_t, the effective discount factor for investments in the country is $(1-\pi_t)/(1+r)$. For all types of projects, investors will maximize current profits PR_t plus the discounted expected value of the project's future payoffs,

$$V_t = \max \{PR_t + \frac{1-\pi_t}{1+r} \cdot E[V_{t+1}]\} \tag{1}$$

where V_t represents the value function. Intuitively, ownership risk is analogous to a higher discount rate.

While this captures the intuition of our approach, the time-varying discount factor in (1) is technically inconvenient. This inconvenience can be overcome by recasting the problem slightly. Note that a once-and-for-all expropriation of a project in period t+1 is economically equivalent to the expropriation of its future profits. Modeling the expropriation event and the probability of future expropriation as state variables that evolve over time allows us to cast the investment problem as one a with constant discount factor, as follows.

The expropriation event is a 0-1 variable ξ_t that indicates whether or not period-(t+1) profits are expropriated. The expropriation probability in a given period is allowed to depend on the prior expropriation probability. This reflects the intuition that there is some persistence in a country's political environment, but surprises may occur. Overall, the evolution of (π,ξ) is

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[9] Partial expropriation could be modeled, but at the cost of complicating the notation.

assumed to follow a bivariate Markov process with transition function $G(\pi_{t+1},\xi_{t+1}|\pi_t,\xi_t)$. If $\xi_{t+1}=0$, π_{t+1} is a function of π_t which ensures the persistence mentioned above. Alternatively, if $\xi_{t+1}=1$ we set $\pi_{t+1}=1$, which assures that $\xi_{t+s}=1$ is an absorbing state for all s>0. This assumption about ξ_t ensures that confiscation in period t eliminates profits in all future periods. Problem (1) can now be rewritten as

$$V_t(\pi_t,\xi_t,..) = \max\{PR_t + \frac{1}{1+r} \cdot \int V_{t+1}(\pi_{t+1},\xi_{t+1},..)dG(\pi_{t+1},\xi_{t+1}|\pi_t,\xi_t)\}, \quad (2)$$

i.e., as a problem with constant discount factor.[10] The dots represent potential additional state variables that depend on the specific project.

We can now confirm that problem (2) is equivalent to problem (1). Since $\xi_{t+1}=1$ is an absorbing state with zero profits, $V_{t+1}(\pi_{t+1},1,..)=0$. Equation (2) can therefore be written in terms of π_t and the conditional density of π_{t+1}, given $\xi_{t+1}=0$,

$$V_t(\pi_t,\xi_t,..) = \max\{PR_t + \frac{1-\pi_t}{1+r} \cdot \int V_{t+1}(\pi_{t+1},0,..)dG(\pi_{t+1}|\xi_{t+1}=0,\pi_t,\xi_t)\}, \quad (3)$$

which confirms that problem (2) is economically equivalent to (1). We will examine three investment decisions in this framework, investment in capital goods, petroleum, and forests.

2.2 Capital Investment

The country is assumed to produce output Y_t from capital K_t and labor N_t according to the production function

$$Y_t = (N_t \cdot H_t)^{\alpha} \cdot K_t^{1-\alpha} \quad (4)$$

where H_t is a productivity index ('human capital'). Labor is assumed to grow at the exogenous population growth rate n. Productivity grows at rate g_H, hence $H_{t+1} = H_t \cdot (1+g_H)$. Productivity growth may depend on the productivity level H_t and on other endogenous or

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[10] Time-varying world interest rates could be modeled similarly for suitable parameterizations of the time-series process of interest rates, but such complications would be distracting for our purposes.

exogenous factors represented by x_t, hence $g_H = g_H(x_t,H_t)$. The variables x_t are assumed to follow a Markov process.[11]

Capital investment is subject to an adjustment cost. The unit cost of I_t units of capital investment in period t+1 is given by a convex function $c(I_t/K_t)$; $c(0)=0$, $c'>0$, $c''>0$. This assumption prevents unrealistically large international capital flows. Capital depreciates at rate δ, so that

$$K_{t+1} = K_t \cdot (1-\delta) + I_t.$$

The representative agent in this economy is both an investor and a supplier of labor. Labor supply is assumed to be perfectly inelastic. Hence, the agent chooses a time-path of investment to maximize the present value of output minus investment cost, taking into account the probability that future profits will be confiscated. The single period payoff is

$$PR_t = (N_t \cdot H_t)^{\alpha} \cdot K_t^{1-\alpha} - [K_{t+1}-K_t \cdot (1-\delta)] \cdot c(K_{t+1}/K_t-(1-\delta)). \tag{5}$$

Let $V(K_t,N_t,H_t,x_t,\pi_t,\xi_t)$ be the value function for this problem, which is defined recursively by

$$\begin{aligned} V(K_t,N_t,H_t,x_t,\pi_t,\xi_t) = \max_{K_{t+1}} \{ & (N_t \cdot H_t)^{\alpha} \cdot K_t^{1-\alpha} \\ & - [K_{t+1}-K_t \cdot (1-\delta)] \cdot c(K_{t+1}/K_t-(1-\delta)) \\ & + \frac{1}{1+r} \cdot \int V(K_{t+1},N_t \cdot (1+n),H_t \cdot (1+g_H(x_t,H_t)),x_{t+1},\pi_{t+1},\xi_{t+1}) \\ & dG(x_{t+1},\pi_{t+1},\xi_{t+1}|x_t,\pi_t,\xi_t) \}. \end{aligned} \tag{6}$$

The optimal policy function for this problem, $K_{t+1}=K^*(K_t,N_t,H_t,x_t,\pi_t,\xi_t)$, satisfies the first order condition

$$c(I_t/K_t) + I_t/K_t \cdot c'(I_t/K_t) = \frac{1}{1+r} \cdot \int V_K \, dG, \tag{7}$$

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[11] Examples of x are schooling levels, the economy's export share (reflecting learning effects), and a time trend. The question of whether these determinants are exogenous or endogenous is not pursued in any detail, as our interest is focused on investments in physical capital. Productivity growth is relevant here only to the extent that it affects the returns to physical capital. Hence, we take an empirical perspective on the question of what determines productivity growth and let the data tell us (in the empirical section) which productivity-related variables have an impact on capital investment.

where V_K denotes the partial derivative of V with respect to K_{t+1} and arguments of G and V_K are omitted for simplicity. This condition states that the marginal cost of K_t should equal the expected present value of its marginal return. The appendix of the paper shows that K^* is increasing in K_t (but less than one-for-one), increasing in H_t and in those elements of x_t that positively affect total factor productivity growth, and decreasing in the expropriation probability π_t. Since PR_t is homogeneous of degree one in K_t, N_t, and K_{t+1}, the value function has the same property. As a consequence the optimal K_{t+1} is also homogeneous of degree one in K_t and N_t.

The empirical objective is to identify the determinants of aggregate capital investment, I_t, for various countries and time periods. To adjust for differences in country size, it is desirable to scale investment by total output, so the dependent variable examined empirically is I_t/Y_t. Using the investment identity $K_{t+1} = K_t \cdot (1-\delta) + I_t$ and homogeneity of K^*, we can write

$$(I_t/Y_t) = K^*(K_t/Y_t, N_t/Y_t, H_t, x_t, \pi_t, \xi_t) - (1-\delta) \cdot K_t/Y_t.$$

This function is not ideal for empirical analysis, however, because the capital stock is not reported for many countries in our data set. To overcome this, we exploit the production function to replace K_t/N_t by $(Y_t/N_t)^{1/(1-\alpha)} \cdot H_t^{-\alpha/(1-\alpha)}$. This yields an investment function of the following form:

$$(I_t/Y_t) = i^*(Y_t/N_t, H_t, x_t, \pi_t, \xi_t). \tag{8}$$

This function is the basis for estimation of the effects of ownership risk on investment. Given our results on K^* the investment output ratio is increasing in elements of x_t that increase productivity growth and decreasing in π_t. The sign of its relationship to Y_t/N_t is ambiguous.

Current productivity, H_t, and the determinants of its growth rate, x_t, are potentially problematic because these variables are imperfectly measured at best. The macroeconomic literature on economic growth suggests a long list of potential proxies for human capital investment, including schooling and trade-related variables. The appropriate use of such proxies in an investment function depends on the process of human capital accumulation, however. Suppose human capital is produced according to a production function

$$H_{t+1} = H_t^{\beta} \cdot h(x_t) + (1-\delta_h) \cdot H_t,$$

where $0 \leq \beta \leq 1$ and $0 \leq \delta_h \leq 1$. If $\beta<1$ and x_t is stationary, human capital will converge to a (stochastic) steady state. In this case a country's mean level of human capital is a weighted average of past investments. Hence x_t and H_t in (8) might be proxied by current and past schooling rates and trade variables.[12]

If $\beta=1$, the long run growth rate of the economy is endogenously given by $g_H = h(x_t)-\delta$ and H_t does not converge to a steady state. Because $g_H(\cdot)$ does not depend on H_t in this case, the economy's optimal K_{t+1} depends on $K_t/(N_t \cdot H_t)$, x_t, π_t, and ξ_t, but not on H_t separately. Using the production function as before to replace K_t, the investment share of output can be written as

$$\left(\frac{I_t}{Y_t}\right) = i^*\left(\frac{Y_t}{N_t \cdot H_t}, x_t, \pi_t, \xi_t\right).$$

Although K_t/N_t and Y_t/N_t do not converge to steady states in this model, I_t/Y_t and $Y_t/(N_t \cdot H_t)$ do. Further, the balanced growth prediction implies that $K_t/(N_t \cdot H_t)$ and $Y_t/(N_t \cdot H_t)$ might show little sample variation. Instead of trying to find proxies for H_t one might therefore omit these regressors and subsume them into the error term. The above regression specification reduces to $(I_t/Y_t) = i^*(x_t, \pi_t, \xi_t)$ in this case, which is a special case of (8). Both of these alternative specifications are examined empirically.

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[12] A potential empirical concern is that an investment model that uses past schooling as proxy for H_t could suffer from an omitted variables bias because some components of H_t are not measured. This would seem especially problematic if the political variables are correlated with output, because output depends on the true H_t, i.e., is correlated with the unobserved components of H_t. Nonetheless, if output is included as regressor, as in (8), the coefficient on π_t will be consistent provided π_t is conditionally uncorrelated with the unobserved components of H_t (conditional on Y_t/N_t.) Only the coefficients on output and on the proxies for human capital would be biased.

2.3 Oil Discovery and Production

Oil discovery and production involve two related but distinct decision problems. First one must decide whether or not to explore in a given country. If exploration occurs and reserves are found, one must then decide what fraction of discovered oil reserves to extract in a given year.

These two decision problems are formalized as follows. Let Γ be the total quantity of oil in the ground in a country at the beginning of time, before any production or exploration takes place. Let R_t and H_t denote, respectively, reserves that are known and reserves that are undiscovered, or 'hidden', at time t.[13] Since the most easily discovered reserves tend to be found first, the marginal discoveries made by additional exploration in a country diminish as exploration proceeds. To capture this effect we assume that the cumulative quantity discovered, $F(\cdot)$, is an increasing, bounded, and concave function of D_t, the cumulative number of wells drilled up to time t: $F(0)=0$, $F'>0$, $F''<0$, and $F(D) \rightarrow \Gamma$ as $D \rightarrow \infty$. Hidden reserves are then $H_t = \Gamma - F(D_t)$.

Known reserves are augmented by new discoveries, $F(D_{t+1})-F(D_t)$, and reduced by production Z_t.[14] Hence,

$$R_{t+1} = R_t + F(D_{t+1})-F(D_t) - Z_t, \tag{9}$$

and $Z_t = R_t-R_{t+1}+H_t-H_{t+1}$.

Oil production is assumed to require specialized capital, variable inputs such as goods and labor, and known reserves. The production function is taken to be Cobb-Douglas with constant returns to scale. Oil extraction capital, $K^0{}_t$, includes pumps, processing equipment, and pipelines. It can only be used to produce oil, and hence is distinct from the general capital

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[13] Some symbols, e.g., H to denote hidden reserves, are defined differently in different sections of the paper. The meaning should be clear from the context. In the model the term 'known reserve' denotes the discovered <u>in situ</u> physical stock of the resource. Data for reserves normally refer to the discovered stock that can be extracted at a cost not exceeding the current price. Our approach to this measurement problem is explained later

[14] Note that R and H do not add up to Γ unless no production has taken place.

stock modeled in Section 2.2. Oil extraction capital becomes productive in the period after it is purchased, reflecting an installation lag.

The Cobb-Douglas assumption implies that the per unit variable cost of production is increasing in the ratio of output to known reserves, and decreasing in the ratio of capital to known reserves. Specifically, unit production cost is $\chi\cdot(Z_t/R_t)^{\beta}\cdot(K^0{}_t/R_t)^{-\upsilon}$, where $\beta>\upsilon>0$ and χ is a function of production function parameters and the wage rate.[15] Oil production labor is assumed to be internationally mobile, so the wage is fixed to each individual country.

To complete the model, the cost function for drilling is assumed to be a convex function of the number of wells drilled in a period, $c(D_{t+1}-D_t)$: $c(0)=0$, $c'>0$, $c''>0$. The price of oil in terms of consumption goods, p_t, is assumed to follow a Markov process with positive autocorrelation.

Taking into account capital investment and depreciation, the current profit from drilling and production is

$$PR_t = Z_t\cdot[p_t - \chi\cdot(Z_t/R_t)^{\beta}\cdot(K^0{}_t/R_t)^{-\upsilon}] + (1-\delta)\cdot K^0{}_t - K^0{}_{t+1} - c(D_{t+1}-D_t) \tag{10}$$

for $\xi_t=0$, and zero for $\xi_t=1$. The implied dynamic programming problem of form (2) is

$$\begin{aligned} &V(R_t,H_t,K^0{}_t,p_t,\pi_t,\xi_t;\Gamma) \\ &= \max_{R_{t+1},H_{t+1},K^0{}_t} \Big\{ p_t\cdot(R_t-R_{t+1}+H_t-H_{t+1}) - \chi\cdot(K^0{}_t/R_t)^{-\upsilon}\cdot\frac{(R_t-R_{t+1}+H_t-H_{t+1})^{1+\beta}}{R_t^{\beta}} \\ &\qquad + (1-\delta)\cdot K^0{}_t - K^0{}_{t+1} - c\big(F^{-1}(\Gamma-H_{t+1})-F^{-1}(\Gamma-H_t)\big) \\ &\qquad + \frac{1}{1+r}\cdot\int V(R_{t+1},H_{t+1},K^0{}_{t+1},p_{t+1},\pi_{t+1},\xi_{t+1};\Gamma) \\ &\qquad\qquad \cdot dG(p_{t+1},\pi_{t+1},\xi_{t+1}|p_t,\pi_t,\xi_t)\Big\}. \end{aligned} \tag{11}$$

It is instructive to divide this optimization problem into a problem of oil production with given reserves and a problem of optimal oil drilling that determines the amount of new reserves.

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[15] See the appendix (available from the authors), where an analogous cost function for forestry is derived.

The optimal production decision equates the price of oil to the marginal production cost plus the marginal opportunity cost of reduced reserves. In the current period, when production capital and reserves are given, production cost is an decreasing function of the capital to reserves ratio K^0_t/R_t. For future periods, when capital can be adjusted, linear homogeneity of the oil production function implies that the optimal ratios of capital to reserves and production to reserves do not depend on the level of reserves. For given oil prices and ownership risk, the optimal scale of future oil production is therefore proportional to the level of reserves. Since future profits are then also proportional to reserves, the present value of profit per unit of reserves is independent of the level of reserves. Given this structure, the overall production and drilling problem can be divided into two parts, a problem of oil production with given reserves and a problem of oil exploration.

In the production problem, we solve (i) for the optimal production rate per unit of known reserves, $z_t = Z_t/R_t$, and (ii) for the optimal ratio of capital to reserves, $k^0_{t+1} = K^0_{t+1}/R_{t+1}$. The solution is characterized by the first order conditions for R_{t+1} (or equivalently, for Z_t) and K^0_{t+1},

$$p_t - \chi\cdot(1+\beta)\cdot\left(\frac{K^0_t}{R_t}\right)^{-\upsilon}\cdot\left(\frac{Z_t}{R_t}\right)^{\beta} = \frac{1}{1+r}\cdot\int V_R\, dG \tag{12a}$$

and $$1 = \frac{1}{1+r}\cdot\int V_K\, dG. \tag{12b}$$

These conditions say, respectively, that: (i) the current net revenue obtained by pumping and selling a unit of the reserve should just equal the expected present value of future profits from leaving it in the ground, and (ii) the marginal cost of oil extraction capital should equal the expected present value of its marginal return. The properties of the solution are detailed in the appendix. We show that the optimal ratio of capital to reserves is a function of the price of oil and ownership risk, $k^0_{t+1} = k^0(p_t,\pi_t)$. This function is increasing in p_t and decreasing in π_t. Intuitively, higher future oil prices provide an incentive to increase k^0 to exploit known resources faster while higher ownership risk increases the effective cost of capital. We also show that the shadow value of reserves depends positively on p_t and negatively on π_t.

The optimal current production rate depends on price, ownership risk, and the capital to reserve ratio, $z_t = z(p_t,\pi_t,k^0{}_t)$. Since capital reduces current production cost, z_t is increasing in $k^0{}_t$. Current production is increasing in ownership risk, because ownership risk reduces the value of leaving reserves in the ground. Finally, z_t is increasing in the current oil price under reasonable assumptions on the driving process for p_t.[16]

In the longer run, ownership risk and oil prices have an additional effect on oil production through the endogenous adjustment of oil capital. Combining the optimal production decision with the equation for the optimal capital-to-reserve ratio yields

$$z_{t+1} = z(p_{t+1},\pi_{t+1},k^0(p_t,\pi_t)) \tag{13}$$

This reduced-form equation for oil production as a function of oil prices and ownership risk forms the basis of our empirical analysis of oil production. Notice that the effects of π_{t+1} and π_t on z_{t+1} are of opposite sign. In practice the ownership risk measure we develop is relatively persistent, making it impossible to separate the effects of current and lagged risk. Consequently, we estimate the production to reserve ratio as a function of current ownership risk and price, and regard the sign of the ownership risk term as indeterminate.

The sign is indeterminate because the effect of ownership risk on production is the result of two opposing forces. On the one hand, an increase in ownership risk triggers an immediate increase in production as firms try to extract and sell reserves ahead of a potential expropriation. On the other hand, ownership risk reduces investment in oil production capital, which raises cost and tends to slow extraction in subsequent periods.[17] While increased

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[16] A high price provides a direct incentive to sell oil now, but if oil prices are autocorrelated, it also raises the shadow value of reserves. Production is increasing in current prices if the direct effect dominates.

[17] Essentially the same intuition underlies Farzin's (1985) result that a higher interest rate may either speed or slow the rate of extraction for a non-renewable resource.

ownership risk should increase oil production in the very short run, the net long run effect is ambiguous. Overall, ownership risk will reduce the rate of extraction in the long run if extraction is highly capital intensive, and vice versa.

The second part of the firm's problem, the drilling problem, is solved by maximizing (11) with respect to H_{t+1}. This determines the optimal level of current drilling, $\Delta D_{t+1} \equiv D_{t+1} - D_t$, as a function of p_t, π_t, initial cumulative drilling, D_{t+1}, and the geological parameter Γ. (Equivalently, this first-order condition can be used to characterize the optimal value of hidden reserves H_{t+1}). The first-order condition is

$$p_t - \chi\cdot(1+\beta)\cdot\left(\frac{K^0_t}{R_t}\right)^{-\upsilon}\cdot\left(\frac{Z_t}{R_t}\right)^{\beta} + \frac{c}{H_{t+1}} = \frac{1}{1+r}\cdot\int V_H \, dG. \qquad (12c)$$

Comparing this to (12a), and noting that $-\partial c/\partial H_{t+1}$ is the marginal cost of discovering a unit of known reserve, (12c) says that the marginal value of a unit of known reserve less the marginal cost of discovering it should equal the marginal value of a unit of the hidden reserve.

The appendix demonstrates that ΔD_{t+1}, the current rate of drilling, is a function of p_t, π_t, hidden reserves, and the geologic parameter:

$$\Delta D_{t+1} = D(p_t, \pi_t, H_t, \Gamma). \qquad (14)$$

Our empirical analysis of drilling is based on this equation. Drilling is increasing in the current price of oil, which is intuitive since higher oil prices increase the value of known reserves. It is also increasing in the size of the remaining hidden reserve, since a larger hidden reserve raises the odds of new discoveries.

The effect of a higher expropriation probability on drilling is indeterminate, however. A high value of π_t reduces the marginal value of known reserves, which discourages drilling, but also reduces the marginal value hidden reserves, which encourages drilling. Since the relative magnitudes are indeterminate, we regard the impact of π_t on drilling activity as an empirical matter. We conjecture, however, that a high value of π_t causes a greater reduction in the marginal value of known reserves than of hidden reserves, in which case greater ownership risk will reduce drilling.

2.4 Forestry Investment

Our analysis of forests regards forest biomass as a form of capital and models the factors that cause it to change. The approach thus conforms to the framework of Section 2.1. For expositional ease forest harvesters are viewed as profit maximizing firms who sell forest outputs on a world market. This is not descriptively accurate in large parts of the world where harvesting forests for salable timber is a minor use of forests. We argue later, however, that the set of determinants identified by the model also applies to forests used mainly for shifting cultivation or fuelwood gathering.

The critical assumptions affecting the exploitation of forests concern their natural growth, the cost of cutting them, and the alternative uses for land that forests occupy. Regarding growth, we assume that the biomass in a forest left undisturbed will converge to a reference level, $\bar{F}$, determined by the country's land area and environmental attributes. Natural growth per period is assumed to decline as the current biomass F_t approaches the reference level $\bar{F}$. The term Z_t once again denotes the relevant output, harvested biomass in this case. The forest biomass in period t+1 is given by

$$F_{t+1} = F_t \cdot [1 + g(F_t/\bar{F})] - Z_t, \qquad (15)$$

where we assume that the growth rate is a declining and convex function:

$g'<0$, $g''>0$, $\partial F_{t+1}/\partial F_t = 1+g+F_t/\bar{F}\cdot g'\geq 1$, and $\partial^2 F_{t+1}/\partial F_t^2 \cdot \bar{F} = g''+2g'<0$.[18]

To obtain harvested biomass one must have standing forest biomass, labor, capital, and possibly materials produced by other sectors of the economy. We assume that the harvesting production function is Cobb-Douglas and that capital and labor enter with the same relative

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[18] For example, $g(f)=g\cdot f^{-\alpha}$ for $0<\alpha<1$ satisfies these restrictions.

weights as for production of other goods. The unit cost of harvesting can therefore be written $c \cdot (Z_t/F_t)^{\beta}$, where c is a constant and $\beta>0$.[19]

While standing, a forest occupies land that has alternative uses, principally agriculture. Conversion of forest land to farming, particularly subsistence farming, is widely regarded as an important cause of deforestation. To incorporate this in a parsimonious way, we assume the demand for agricultural land is perfectly inelastic, determined by the intensity of food demands, and note that converting part of a country's land to agriculture lowers $\bar{F}$, the level its forest biomass can potentially reach. Accordingly, we regard $\bar{F}$ as partially determined by factors that determine the demand for agricultural land.[20]

The total profit from Z_t units of harvested biomass can be written

$$PR_t = Z_t \cdot [p^F{}_t - c \cdot (Z_t/F_t)^{\beta}], \tag{16}$$

where $p^F{}_t$ denotes the price of harvested biomass in terms of the consumption good. In the context of political risk, equation (16) applies for the no-expropriation state $\xi_t=0$, while $PR_t=0$ for $\xi_t=1$. The relative price of wood is assumed to follow a Markov process.

The optimal forestry decision problem is then the solution to a dynamic programming problem of form (2),

$$\begin{aligned} V(\pi_t,\xi_t,F_t,p^F{}_t;\bar{F}) = \max_{F_{t+1}} \{ & p^F{}_t \cdot (F_t+F_t \cdot g(F_t/\bar{F})-F_{t+1}) \\ & - c \cdot \frac{(F_t+F_t \cdot g(F_t/\bar{F})-F_{t+1})^{1+\beta}}{F_t{}^{\beta}} \\ & + \frac{1}{1+r} \cdot \int V(p^F{}_{t+1},F_t,\bar{F},\pi_{t+1},\xi_{t+1})\, dG(p^F{}_{t+1},\pi_{t+1},\xi_{t+1}|p^F{}_t,\pi_t,\xi_t) \}. \end{aligned} \tag{17}$$

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[19] The derivation is in the appendix (available, separately, from the authors).

[20] A more detailed treatment of land conversion would require modeling cleared land as a separate state variable, complicating the analysis significantly. We expect the resulting empirical model would be essentially the same as the one we derive.

The optimal policy function for this problem, $F_{t+1}=F^{*}(\pi_t,\xi_t,F_t,p^F{}_t;\bar{F})$, satisfies the first order condition

$$p^F{}_t - (1+\beta)\cdot c\cdot\left(\frac{F_t+F_t\cdot g(F_t/\bar{F})-F_{t+1}}{F_t}\right)^{\beta} = \frac{1}{1+r}\cdot\int V_F\, dG, \tag{18}$$

where V_F denotes the partial derivative of V with respect to F_{t+1}. The appendix shows that F_{t+1} is an increasing function of F_t and $\bar{F}$, and a decreasing function of π_t and $p^F{}_t$. The proportionate change in forest cover, $(F_{t+1}-F_t)/F_t$, can be written

$$(F_{t+1}-F_t)/F_t = f(\pi_t,p^F{}_t,F_t;\bar{F}). \tag{19}$$

It is decreasing in π_t, $p^F{}_t$, $p^A{}_t$, and F_t, and increasing in $\bar{F}$. This policy function is the basis for subsequent empirical analysis.

In many parts of the world the dominant uses of forest biomass are fuelwood and nutrients for shifting cultivation, not commercial timber. The determinants of forest cover identified by the model arguably continue to apply, however. The initial and maximum forest cover, F_t and $\bar{F}$ are clearly relevant as are the unit value of biomass, $p^F{}_t$, and the demand for food. More importantly, fuelwood gathering and shifting cultivation use the standing forest as a stock, or capital-type input, to produce harvested biomass. Expropriation risk, π_t, lowers the incentive to maintain forest capital and hence should result in lower stocks.[21]

3. ESTIMATION

The first empirical task is to estimate an economy-wide investment function that highlights the role of political factors related to expropriation risk. The resulting estimates are used to form an index of ownership risk for use in empirical analysis of oil exploration, oil production, and changes in forest stocks.

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[21] When forests are used mainly as sources of fuelwood or farming nutrients, ownership may be by families, clans, or villages rather than profit maximizing firms. The effect of insecure ownership on investment decisions is qualitatively the same, however.

3.1 Political Attributes Examined

We expect an investor's risk in a given country to be related to its political stability and to the type of government in power. By hypothesis, risk is high when government is too unstable to enforce laws and carry out policies predictably, or lacks the power to control activity in the countryside. As potential indicators of political instability, we examine: major constitutional changes, revolutions, political assassinations, purges, and guerrilla warfare.[22] Data on these events are taken from Banks (1990) and Table 1 explains how they are defined.[23]

Table 1. Definitions of political instability measures

Revolution: An attempted illegal or forced change in the top government elite, or armed rebellion intended to gain independence from the central government.

Major constitutional change: A basic alteration in a state's constitutional structure, e.g., altering the roles of different branches of government, but excluding minor constitutional amendments.

Political assassination: Any politically motivated murder or attempted murder of a high government official or politician.

Political purge: A systematic elimination, by jailing or execution, of political opposition within the ranks of the regime or the opposition.

Guerrilla warfare: The presence of any armed activity, sabotage, or bombings carried on by independent bands of citizens or irregular forces and aimed at the overthrow of the present regime.

Source: Banks (1990)

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[22] We do not include the degree ownership of government ownership of capital goods or resources in empirical models because available data are far from complete. We expect government instability to lower investment in government owned assets as well as private property because, viewed broadly, government is a conduit for promoting the interests of specific groups in society. Government investment is attractive to the group in power only if the conduit is expected to remain stable so that the party who promotes a public investment is assured of receiving the ultimate reward. See Boyce (1993, pp. 226, 226) for supporting evidence from forest use in the Philippines.

[23] Events are represented by dummy variables, defined to equal one if at least one such event occurred in a given year. Barro (1991) and others have used the sum of coups and revolutions as a measure of violence. In the Banks (1990) data set, coups are essentially successful revolutions. Using the sum of the two as an instability indicator amounts to assigning successful revolutions twice the impact of unsuccessful revolutions.

Instability aside, the type of government regime in power might also matter to investors. As Olson (1993, p. 572) points out, in systems ruled by individuals or cliques the investor's property claim depends on remaining in favor with the ruling group and on the group's ability to retain power. Also, such systems are arguably vulnerable to radical change, since deposing a single person or small cadre may alter the country's entire system of property claims. Accordingly, we hypothesize that the average citizen's claim to property is weaker in countries ruled by individuals and dominant elites, and stronger in countries ruled by impersonal laws and institutions. To capture such effects, we assign each country in each year to one of six political regimes.

The basis for defining regimes is information on the type of chief executive (premier, president, military officer, monarch, and other), the method of selecting the chief executive (direct election, indirect election, and non-elective,) and the existence or effectiveness of the legislature (effective, partially effective, ineffective, and non-existent.)[24] Figure 1 describes these definitions and gives percentages of the sample in each. We distinguish parliamentary democracy from other democracies because a parliamentary executive is drawn from the ranks of the legislature, which may indicate that the legislature wields significant power. Non-parliamentary democracies are largely presidential systems. Monarchies are defined separately because several major oil producing countries are monarchies. Regime type 6 is a mixture of countries in anarchy, protectorates, and other forms of government.[25]

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[24] The 'other' chief executive category includes some cases in which no effective chief executive can be identified and others in which the person shaping the country's policies holds no formal government post. Banks (1990) terms a legislature effective when it exercises substantial authority regarding taxation and spending and the power to override executive vetoes. A legislature is partially effective when its power is outweighed, though not eclipsed, by the executive. A legislature is ineffective if it is essentially a 'rubber stamp', or if domestic turmoil or executive action prevents it from functioning.

[25] These regime definitions correspond roughly to degrees of 'inclusiveness,' as that term is used by McGuire and Olson (1996), with the democratic regimes (R1 and R2) being more inclusive than the non-democratic regimes (R3-R6.)

Selection and type of executive:

<table>
<tr><th></th><th colspan="2">Elected</th><th colspan="3">Nonelected</th></tr>
<tr><th>Effectiveness of legislature:</th><th>Premier</th><th>Nonpremier</th><th>Military</th><th>Monarch</th><th>Other</th></tr>
<tr><td>Effective or partially effective</td><td>R1
31.3%</td><td>R2
17.6%</td><td rowspan="2">R3
8.7%</td><td rowspan="2">R5
6.6%</td><td rowspan="2">R6
10.3%</td></tr>
<tr><td>Ineffective or nonexistent</td><td colspan="2">R4
25.5%</td></tr>
</table>

R1. Parliamentary democracy
R2. Nonparliamentary democracy
R3. Military dictatorship
R4. Strong executive
R5. Monarchy
R6. Other

Figure 1. Definitions of Regimes

3.2 Capital Investment

Our empirical model of capital investment is based on equation (8), which expresses the investment/output ratio (I_t/Y_t) as a function of output per worker (Y_t/N_t), human capital (H_t), exogenous factors determining productivity growth (x_t), and the expropriation probability (π_t). Data on I_t/Y_t and Y_t/N_t were taken from Summers and Heston (1991). The ideal H_t variable would be an index of the human capital stock per worker. Data on stocks are unavailable, however, so we use a flow measure as a proxy, the ratio of secondary school enrollment to population from Banks (1990). The empirical investment literature suggests adding an economy's openness, the sum of imports and exports divided by GDP (Levine and Renelt, 1992). Summary statistics for these economic variables are shown in Table 2.[26]

Table 2. Summary statistics

	mean	std. dev.
Growth theory variables:		
Investment/output (percent)	16.34	9.18
Real output per worker (1990$)	9,320	8,778
Secnd'y school enrollment	.0289	.0249
Openness (percent)	59.21	40.09
Instability measures:		
Revolutions	.1426	.3497
Political assassinations	.0909	.2875
Purges	.1181	.3227
Guerrilla warfare	.1783	.3828
Constitutional changes	.0992	.2799

[26] Investment and GDP data and the openness index are from the 1995 update of the Penn world table. The openness index and secondary school enrollment per capita were not available for all of the country-year pairs for which investment and political data are reported. Rather than drop these observations, the missing values for these two variables were set to zero and a dummy variable was defined for each, taking on the value of one when the variable is missing. This is equivalent to setting missing values for these variables at the means of the subsamples for which they are missing. Coefficients for these dummy variables are not reported, but are available on request.

Other considerations dictate inclusion of two additional variables. First, investment is expected to fluctuate over the business cycle for reasons not spelled out in the model, so the average unemployment rate in the G7 countries is included as a regressor. Second, investment in OPEC nations was significantly higher than our model would indicate. Modeling this would be distracting, so we take the purely pragmatic approach of including a dummy variable defined to equal one for OPEC members.[27]

Table 2 also reports summary statistics for the five political events examined. In preliminary analysis we found that long lags of political events have an impact on investment and that these effects do not seem to decline over time. This suggests that investors have some underlying notion of a permanent country risk that is best measured empirically by the long run frequency of such events. It is plausible, however, that perceived risk might rise temporarily after an event occurs. To model these short- and long-run linkages in a parsimonious way we include the average frequency of each political event, by country, and define dummy variables for the temporal occurrence of individual events in the current or preceding year.[28] The effect of a specific event on investment might further depend on the type of regime in power, e.g., a revolution may be very damaging in a strong 'rule of law' regime since it threatens to upset an otherwise secure system of ownership, but do little damage in a dictatorship where property claims are already weak. Regime-instability interactions are examined to allow for this.

Our treatment of constitutional change is more complex. Banks (1990, p. 17) records only <u>major</u> constitutional changes, e.g., "adoption of a new constitution that significantly alters the prerogatives of the various branches of government," and excludes ordinary amendments. Such constitutional changes often coincide with a change in the type of political regime. One

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[27] Unexpectedly high wealth during the 1970s and 1980s may have caused OPEC nations to invest domestically to smooth consumption.

[28] By using full sample averages of event frequencies we use information from later years to explain investment in the early years of our sample. Our interpretation is that investors know the underlying permanent risk, while we have to estimate it.

would expect constitutional change that switches the regime from democracy to dictatorship to have a much different effect on investment than one that runs in the opposite direction. To allow for this the constitutional change variable was interacted with a set of dummy variables indicating the regime in effect at the start and at the end of the year in which the constitutional change occurred.[29] To reduce the dimensions of the resulting model, regimes 3 through 6 were aggregated into a single, composite regime in forming these interactions, so nine interactions are defined.[30] The investment model includes the average frequency plus dummies for current and lagged changes for each of these nine constitutional change variables.

Table 3 presents OLS estimates of the investment model. Alternative specifications and estimation methods were examined. The ownership risk index, our sole reason for estimating the investment equation, was found to be robust to these changes, however. Hence we report the OLS results for expositional simplicity, and comment only briefly on results obtained from the variants we examined. The dependent variable in Table 3, I/Y, is a percentage with a possible range of 0 to 100. To avoid simultaneity problems we used five year lags, rather than contemporaneous values, for output per worker, capital per worker, secondary school enrollment, and openness.[31] Each of the growth theory variables is highly significant and of expected sign. The elasticities of investment with respect to these variables, evaluated at sample means, give an idea of the quantitative importance of each term. The elasticities are .14 for real output per worker, .11 for secondary schooling, and .18 for openness.

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[29] For example, the first such variable equals one for a given country in year t if the country began year t in regime 1, ended it in regime 1, and a constitutional change occurred during year t.

[30] Regimes 3 through 6 can be characterized as less democratic than regimes 1 and 2. These four were aggregated for examining constitutional changes because they have similar investment rates, after controlling for non-political factors.

[31] Using lags of different lengths has little effect on the resulting risk index. For example, estimating alternative models with one versus five year lags of endogenous terms yielded indexes that have a simple correlation of .997.

Table 3. Investment model

Dependent variable:	Investment/output coeff.	t-stat.
Growth theory variables:		
Output per worker	.00024	(12.81)
Secondary school enrollment	60.97	(9.70)
Openness	.0491	(14.32)
G7 unemployment rate	-.5893	(-7.42)
OPEC	4.0520	(8.88)
Regimes:		
R1 Parliamentary democracy	8.5132	(15.84)
R2 Nonparliamentary democracy	4.5075	(7.96)
R3 Military dictatorship	3.9304	(6.50)
R4 Strong executive	4.8567	(9.37)
R6 Other	4.4638	(7.61)
Average frequencies of instability events:		
Revolutions	-.1419	(-10.39)
Political assassinations	.0282	(1.65)
Purges	.1519	(10.60)
Guerrilla warfare	.0008	(0.09)
Constitutional change, R1R1	-.7105	(-7.91)
Constitutional change, R1R2	-.9166	(-5.28)
Constitutional change, R1RA	.0983	(0.84)
Constitutional change, R2R1	.9896	(2.01)
Constitutional change, R2R2	.1533	(2.40)
Constitutional change, R2RA	-.7781	(-5.44)
Constitutional change, RAR1	-.2514	(-0.91)
Constitutional change, RAR2	.9481	(4.91)
Constitutional change, RARA	-.1988	(-9.30)
Current and lagged instability events:		
Revolutions(t)	.0923	(0.24)
Revolutions(t-1)	-.2341	(-0.61)
Political assassinations(t)	-.8457	(-2.02)
Political assassinations(t-1)	-7997	(-1.91)

Table 3. Investment model (continued)

Dependent variable:	Investment/output coeff.	t-stat.
Current and lagged instability events (cont.):		
Purges(t)	-.3964	(-0.99)
Purges(t-1)	-.2161	(-0.56)
Guerrilla warfare(t)	.6078	(1.67)
Guerrilla warfare(t-1)	.5701	(1.57)
Constitutional change, R1R1(t)	-.9769	(-0.60)
Constitutional change, R1R1(t-1)	-2.2892	(-1.44)
Constitutional change, R1R2(t)	-4.6587	(-1.82)
Constitutional change, R1R2(t-1)	1.9452	(0.76)
Constitutional change, R1RA(t)	-3.4171	(-1.78)
Constitutional change, R1RA(t-1)	-.3751	(-0.19)
Constitutional change, R2R1(t)	.3871	(0.06)
Constitutional change, R2R1(t-1)	-4.8879	(-0.78)
Constitutional change, R2R2(t)	.9384	(0.74)
Constitutional change, R2R2(t-1)	-.4344	(-0.34)
Constitutional change, R2RA(t)	-.6572	(-0.40)
Constitutional change, R2RA(t-1)	-.4483	(-0.27)
Constitutional change, RAR1(t)	3.5587	(0.93)
Constitutional change, RAR1(t-1)	-1.7902	(-0.49)
Constitutional change, RAR2(t)	-.5313	(-0.22)
Constitutional change, RAR2(t-1)	-1.7043	(-0.71)
Constitutional change, RARA(t)	-.0939	(-0.18)
Constitutional change, RARA(t-1)	.0235	(0.05)
Constant	8.7786	(13.49)
N	3225	
R^2 adj.	.54	

Note: R5, Monarchy, is the default regime. The term 'Constitutional change, R1R1' refers to a constitutional change that originates in regime 1 and leaves the country in regime 1, and so forth. RA denotes the composite composed of regimes 3-6. The terms (t) and (t-1) refer to current values and lags of political event indicators.

The political regime dummies sum to unity so one regime, monarchy, was excluded in estimation. Current and lagged regime indicators are highly correlated because regimes tend to persist, so only current regime indicators are included. After controlling for growth theory variables, parliamentary democracy is significantly more favorable to investment than any other regime. Monarchy, the default regime, is significantly less favorable than any other category. The regime effect is quantitatively important: the difference in investment between highest and lowest regime coefficients is 8.5 percent of national output, or about one-half of the mean investment rate for the entire sample.[32]

The average frequencies of instability events are coded to vary from 0 to 100; we loosely interpret them as annual probabilities of occurrence in each country. Accordingly, the effect of a one percentage point increase in the annual probability of a revolution is to cut the investment rate by 0.14 percentage points. The anomalous positive sign for purges is discussed shortly. Regarding constitutional changes, the signs of statistically significant terms generally coincide with expectations. In a parliamentary democracy (R1), increasing the probability of a constitutional change generally reduces investment significantly. In a non-parliamentary democracy (R2), a higher probability of switching to the parliamentary regime raises investment, while a higher probability of switching to the less democratic composite regime lowers it. We have no explanation for the finding that a higher probability of constitutional change that keeps the regime in R2 tends to raise investment, but the effect is small. Starting in the less democratic aggregate regime category (labeled RA in Table 3,) increasing the probability of a switch to non-parliamentary democracy raises investment substantially, while a greater probability of constitutional change that leaves the regime

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[32] The coefficients for regimes 2, 3, 4, and 6 are not significantly different from one another. For these regimes, the political factors that are salient for investment are picked up by the average frequencies of instability events. When average event frequencies are excluded from the model the regime coefficients become: 8.5 for parliamentary democracy, 5.9 for non-parliamentary democracy, 4.2 for strong executive, 2.8 for military dictatorship, and 2.7 for other. The hypothesis of equality can be rejected for each pair of regime coefficients, except military dictatorship and other.

unaltered has a small negative effect. The negative coefficient for switching from the aggregate regime to parliamentary democracy is unexpected, but the effect is insignificant.

Current and lagged instability event variables are insignificant except for political assassinations, where the effect is negative and fairly large. Constitutional changes that switch the regime away from parliamentary democracy are negative and approach significance.[33]

Regarding the puzzling effect of purges, our analysis of purge-regime interactions revealed a possible explanation. The positive association between purges and investment occurs primarily in regime 2, non-parliamentary democracy. A check for 1960, 1970, and 1980 shows that regime 2 includes two groups of less developed nations, one African and one Latin American. The group of Latin American countries in regime 2 had a much higher incidence of purges than the African nations in regime 2, and also had higher investment shares. Thus purges may be capturing the influence of an omitted political attribute that effectively distinguishes some African from some Latin American nations, rather than anything causal.[34]

An index of ownership security, a monotone decreasing function of π_t, was formed by multiplying together the political variables and coefficients in Table 3 and summing.[35] We use this variable as a proxy for π_t in models of oil exploration, oil production, and forestry.[36] In

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[33] Adding higher order lags of event occurrences did not result in significant coefficients. The possibility of interactions between regimes and events was examined by replacing each current event indicator by a set of interactions between it and the six regime dummies. The hypothesis that the interaction coefficients are identical was then tested. In each case the hypothesis of equal coefficients could not be rejected, so the interactions were dropped in favor of the single event indicator.

[34] This conclusion is bolstered by results from country specific regressions of the investment share on growth theory variables plus current and lagged purges. These were estimated to reveal whether investment in a given country increases following a purge. Among 14 countries that experienced more than one purge while in regime R2, 23 of the 28 coefficients for purges (14 current and 14 lagged terms) were negative, and none of the five positive coefficients were significant.

[35] The index is available from the authors on request. The OPEC dummy variable was not considered a political variable, though one might argue that the OPEC investment effect in Table 3 arises from political factors. In any event our results are not highly sensitive to this choice. We formed a second index by including the OPEC dummy with the political factors and found the correlation between two indexes to be .9648.

[36] It is possible that ownership risk is measured with error because our empirical model of investment omits some relevant factors. When inserted into regression models for petroleum and forests, this will bias the coefficients for the political index toward zero and toward a conclusion that political factors do not matter.

the overall sample, the index has a mean of 12.62 and a standard deviation of 4.28. The cross country average declined steadily between 1955 and 1977, from 14.44 to 12.30, due mainly to the formation of new, relatively risky, nations. For countries in the sample throughout the period, the average risk index remained roughly constant.

Several alternatives to the pooled OLS specification for investment were examined. These are: including fixed effects for unobserved heterogeneity across groups of countries, correcting for within-country serial correlation, and including a riskless real interest rate. Our basis for comparing these alternatives is the effect they have on the ownership index, since this is our primary focus. In all cases the alternatives yielded indexes that are correlated with the OLS index at .91 or better, and in most cases the correlation is above .97.[37] Since the OLS results appear to be robust, we chose to rely on them for simplicity.

3.3 Oil Discovery

Our analysis of oil discovery is based on (14), which expresses the drilling rate as a function of P_t, π_t, H_t, and Γ. The last two terms, the initial geologic abundance of the resource and the amount of hidden reserves remaining, raise a problem because they are not observed. Together, they capture the positive effect of favorable geologic conditions on oil drilling--more drilling occurs in countries where oil is abundant. To over overcome this problem, we proceed by inferring geologic abundance from a model of drilling success rates.

Other coefficients in these models will be biased only if the variables in question are correlated with the measurement error for ownership risk.

[37] Including fixed effects for continents yielded coefficient estimates very similar to those in Table 3. The resulting index is correlated with the OLS index at the .974 level. Following the same procedure with random effects for continents yielded a correlation with the OLS index of .999. Because the average event frequencies are fixed by country, and the regime dummies are nearly fixed by country, estimation with country specific fixed effects is not possible. Correcting for within-country, first-order serial correlation (in a slightly simplified investment model) yielded an ownership index that is correlated with the OLS index at the .911 level. Finally, allowing a real interest rate variable to enter, a term our theoretical model assumed constant for analytical convenience, yielded a significant negative coefficient; the resulting ownership index is correlated with the OLS index at the .999 level, however.

The drilling success rate is the fraction of wells drilled that successfully strikes oil. We postulate that the drilling success rate in a given country depends on geologic abundance (H and Γ) and on economic factors. Economic factors are relevant because a well that strikes a modest amount of oil may be logged as a dry hole unless prices and costs are favorable. Among relevant economic variables, the price of oil, price risk, and drilling cost levels are captured by yearly fixed effects since they vary over time but not across countries. Ownership risk is relevant for the same reason price and cost are, and was included. Geologic abundance is treated as a country specific fixed effect. The success rate model was estimated by OLS using data for 30 countries over 1957-1988. The country fixed effects were retained for use as a geologic abundance variable.[38]

The drilling rate model can now be estimated directly. The dependent variable is wells drilled per year and the regressors include the risk index, price, and geologic abundance. Two additional independent variables, the average gravity of a country's crude oil and the average depth of its reserves, are included to control for differences in crude oil quality and differences in drilling and production costs. A country's land area was also included since, given any success rate, geologic abundance is greater in larger countries. Since OPEC nations attempted to restrict output during 1974-1985 we include a dummy variable for OPEC nations during these years and anticipate a negative coefficient. Finally, yearly fixed effects were included to capture temporal changes in price risk and technology.

Table 4 reports OLS estimates of the drilling model, with yearly fixed effects omitted to save space. Experimentation with linear models indicated that the relationship between drilling and the risk index is non-linear, so a log-log specification was used. Recall that the risk variable indicates ownership security, the inverse of π_t. It is highly significant and positive, so drilling is more extensive in less risky countries. The predicted change in drilling from a one

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[38] Available data do not report whether 'dry holes' were intended for oil or gas, so we can only calculate an overall success rate for oil and gas combined.

standard deviation change in the index is 46 percent, so the effect is large. Price and geologic abundance are also significant and of expected sign. The OPEC dummy is of expected sign and plausible magnitude, but insignificant.[39]

Table 4. Drilling models

Dependent variable:	Log (wells/year)	
	coeff.	t-stat.
Log (ownership security)	1.4523	(7.54)
Geologic abundance (fixed effect)	4.6996	(9.95)
Log(price)	.4599	(2.53)
OPEC 1974-1985	-.2359	(-1.16)
Log(API gravity)	-2.1293	(-5.47)
Log(depth)	-.8079	(-5.74)
Log(land area)	.7303	(19.18)
Constant	4.8263	(2.25)
N	643	
R^2 adj.	.52	

Notes: Data sources are *World Oil* for drilling rates and *Oil and Gas Journal* for gravity and well depth information. The sample used for estimation excludes communist countries, because their data on production and reserves appear unreliable. Available data do not separate each country's onshore and offshore operations, so countries with offshore production exceeding 25 percent of total output were excluded, because onshore and offshore operating costs are very different. Data on gravity are incomplete. The variable used is the average API (American Petroleum Institute) gravity for the country's top 10 producing onshore fields as of 1970, or a year close to 1970. Gravity is a chemical attribute of a country's petroleum, so it typically will be roughly constant over time. When no gravity data are available for a given country, the missing value was coded as a zero and a dummy variable was defined to equal one for such missing values. Average depth is recorded as the average depth of each country's onshore oil in 1970.

[39] The risk index does not consider OPEC membership as a political variable. Revising the index to include the OPEC dummy and re-estimating the drilling model has the following effect: the ownership security coefficient falls to 1.06 (t=5.1) and the OPEC coefficient falls to -.4860 (t=2.34). Since drilling is relatively low in OPEC countries, including OPEC in forming the index reduces the positive correlation between the index and drilling.

We experimented with alternatives to the pooled OLS model and here summarize the results obtained for the variable of central interest, ownership security. Including fixed effects for continents reduced its coefficient by about one-third, to 0.99 with a t-statistic of 4.84.[40] We found significant first-order serial correlation in the OLS residuals. This was substantially reduced by including a time trend, however, which may capture changes in drilling technology of input prices. Correcting for serial correlation in the model with the trend reduced the index coefficient by about one-fourth, to 1.15 with a t-statistic of 3.87.

Three additional variants were examined. To test sensitivity to outliers the model was estimated by minimum absolute deviations. It was also re-estimated using White's method for obtaining consistent standard errors in models with heteroskedasticity. Finally, a real interest rate variable was added to the basic specification. None of these alternatives changed the ownership security coefficient or its standard error by as much as 5 percent.

3.4 Oil Production

The model for oil production is based on equation (13), which expresses the production/reserve ratio as a function of price and ownership risk. The effect of price should be positive. The effect of ownership risk is theoretically ambiguous because it results from two opposing forces. Higher risk implies heavier discounting of future returns, tending to hasten production in the short run, but lowers the capital intensity of oil production, tending to slow production in the long run. For reasons spelled out in the drilling section, the average depth and API gravity of a country's crude oil are also included. The production model is competitive and may not capture the behavior of OPEC nations during the period when they attempted to control output by assigning production quotas. Since these quotas and the degree to which they were obeyed presumably varied from member to member, we define a dummy variable for each OPEC member that equals one during 1974-1985. Experimentation

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[40] Including country fixed effects renders the index insignificant, since the index varies primarily across, rather than within, countries.

with linear models indicated a non-linear relationship between the risk index and the production/reserve ratio, so a log log form was used.[41]

Table 5. Oil production models

Dependent variable:	Log(output/reserve)	
	coeff.	t-stat.
Log(ownership security)	.7832	(9.71)
Log(price)	.0587	(1.32)
OPEC dummies (1974-1985):		
Algeria	-.2160	(-1.06)
Ecuador	.3941	(2.05)
Indonesia	-.2180	(-1.07)
Iran	-.8317	(-4.23)
Iraq	-.9549	(--5.14)
Saudi Arabia	-.7947	(-4.01)
Log(API gravity)	-.4234	(-2.40)
Log(depth)	-.0009	(-.0007)
Constant	-3.4780	(-3.11)
N	687	
R^2 adj.	.22	

Notes: Communist countries and countries with more than 25 percent of production from offshore reservoirs were excluded for reasons explained earlier. A production minimum of 1,000 barrels per day was imposed for inclusion in the sample, since smaller output levels might indicate experimental operations. Israel and Egypt were excluded because Israel occupied and produced from Egypt's Sinai fields during part of the 1970s. No data are published on reserves in these specific fields or on the scheduling of their eventual return to Egypt. Other observations were excluded for reasons related to the phase-in of production following major discoveries. Following a large discovery, production may not reach its intended level for several years while equipment and pipelines are being installed. This can cause a country's production/reserve ratio to appear abnormally low if it makes several discoveries, even if the ratio for each new field eventually rises to a normal level when installation is complete. This problem was dealt with by dropping observations when either: (i) the current reserve exceeds last year's reserve by 50 percent or more, or (ii) next year's output exceeds this year's output by 50 percent or more.
Among dummies for OPEC members, the default is Venezuela. OPEC dummy coefficients could not be estimated for Gabon, Kuwait, Libya, Nigeria, Qatar, and United Arab Emirates due to insufficient data.

[41] Reserves in the theoretical model refer to a physical measure, whereas the measured reserves reported in available data refer to quantities of oil that can be produced at a cost not exceeding the current price. The dependent variable used in empirical analysis is thus the ratio of production to measured reserves. Multiplying both sides of equation (13) by the ratio of physical to measured reserves gives the appropriate model for the dependent variable we actually observe, but the ratio of physical to measured reserves should now appear as an independent variable. We expect his ratio should to be a function of oil price and determinants of production cost, however. Since price and cost factors are already included as regressors, the empirical model remains correct.

Table 5 reports OLS estimates of the production model.[42] Ownership security is highly significant and positive, so production is more rapid in safe countries than risky countries. Evidently, the dominant effect of ownership risk is to discourage investments in oil extraction capital. This indirectly confirms Farzin's (1985) theoretical finding, that higher discount rates can slow extraction of a non-renewable resource. A one standard deviation change in the index corresponds to a 25 percent change in production, so the effect is large.[43] Price has the expected sign but is insignificant. The OPEC dummies show significantly lower output rates for Iran, Iraq, and Saudi Arabia during 1974-1985; surprisingly, Ecuador's output was significantly higher.

Several alternatives to the pooled OLS approach were examined, with the following effects on the ownership security coefficient. Including fixed effects for continents reduced the coefficient slightly, to .6390 with a t-statistic of 6.41. We found significant first-order serial correlation in the OLS residuals and, once again, including a trend in the model mitigated it. Correcting for serial correlation in the model with the trend reduced the ownership security coefficient slightly, to .7008 with a t-statistic of 6.13.

We also examined the effect of: estimating by minimum absolute deviations (to reduce the effect of outliers,) using White's method to estimate standard errors, and including a real interest rate. The largest effect on the ownership coefficient was to reduce it from .7832 to .6419; the resulting t-statistics ranged from 8.04 to 10.99.

The index varies widely across countries but is relatively stable over time within countries so its coefficient should primarily capture long run effects, which is consistent with

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[42] Yearly fixed effects were examined to allow for factors that change over time but are common to all countries, but failed a test of joint significance.

[43] Replacing the 1975-1985 OPEC member dummies by OPEC dummies that equal one in every period improved the model's fit and reduced the coefficient for the index to .4148 (t=5.56.) These results are not emphasized because we see no clear reason to dummy out OPEC members prior to 1974. Redefining the risk index to include OPEC membership as a political variable changes the coefficient on the index to .4762 (t=5.0) and OPEC coefficient to -.6582 (t=-7.25.)

its positive sign.[44] To get a better indication of short run effects, we estimated within country models that include the index, oil price, OPEC, and a time trend as regressors. The risk index was significant for seven of the 25, with four positive and three negative coefficients. The fact that these are mixed, whereas the relationship was strongly positive for the full sample, suggests that increased risk has a production enhancing component in the short run. Also, the significant negative coefficients (indicating faster production with increased risk) are for Iran, Iraq, and Oman.[45] Relative to other countries in the sample, the ownership security index is very low on average and highly changeable for these three, which may explain why their production responses to risk seem to be dominated by short run considerations.

3.5 Deforestation

Our empirical analysis of forests is based on equation (19), which expresses the proportionate change in the forest stock as a function of ownership security, the price of forest biomass, the existing forest stock, environmental factors, and the intensity of demand for agricultural land.

Data on forest stocks by country are available for two years, 1980 and 1985, so only a single cross section on stock changes is available. Forest stock is measured by the area of land covered by forests, as data on the average density of biomass are not available. The ownership risk index was averaged by country over 1980-1985 for inclusion in the model. Two variables capture environmental determinants of $\bar{F}$, a country's annual internal renewable water resources and the length of its coastline, both scaled by land area. For forest product prices we use 1983 unit values of saw logs and veneer logs for coniferous and non-coniferous wood, separately. To reflect demand for agricultural land, we include 1980-1985 average population

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[44] Accordingly, estimating the model with country fixed effects reduced the index coefficient to insignificance. It also revealed that the between countries correlation coefficient is three times as large as the within countries correlation coefficient.

[45] West Germany, Mexico, Peru, and Turkey had significantly positive coefficients.

density. This variable also allows us to test the common claim that population pressure is the primary cause of deforestation.

Table 6. Forest models

Dependent variable:	Proportionate change in forest stock	
	coeff.	t-stat.
Ownership security	.0056	(3.37)
Initial forest stock	.0964	(3.50)
Water resources/land area	-.0189	(-0.03)
Coastline/land area	-.0320	(-2.06)
Population density	.0067	(1.12)
Sawlog price, coniferous	-.0226	(-1.42)
Sawlog price, non coniferous	-.0018	(-1.60)
Constant	-.1199	(-3.70)
N	71	
R^2 adj.	.39	

Notes: The primary source is data from the U.N.. forest resource assessment conducted for 1980 and extended to 1985 (FAO, 1988). This source reports 'forest cover' for 129 countries in 1980, but reports data for only 84 countries in 1985. A second source (FAO 1986) provides 1980 and 1985 data on 'forest and woodland' area, a closely related measure of land use. Data from this second source were used, in conjunction with available 1980 and 1985 data from the primary source, to fill in the missing 1985 observations. Details are available from the authors. Data from the 1990 U.N. forest assessment are considered unreliable and are not used; see Cropper and Griffiths (1994). The sample used for estimation excludes a country if its 1980 forest cover was less than 5 percent of land area or if 'open forests' account for more than one-half of its total forest cover. Open forests include grasslands, with tree cover as sparse as 10 percent, such as savannah or veldt regions of Africa. 'Closed forests' have at least 25 percent tree cover and no continuous grass cover.

Table 6 reports OLS estimates of the forest model. The ownership index indicates that less risky countries experience greater forest growth; equivalently, more risky countries experience greater deforestation. A one standard deviation difference in the index is associated with a 2.32 percent difference in the five year change in forest stock, which is about half of the mean change in forest stocks for the sample.

Contrary to the model's prediction, the change in forest cover is increasing in the initial forest stock. The likely reason is that initial forest cover is correlated with omitted environmental or climate factors that determine a country's suitability for growing trees. Only one of the two environmental measures is highly significant. Forest product prices have the anticipated signs but are not highly significant. The sign of population density is unexpected, but the coefficient is not significant.[46]

Again, we tested the sensitivity of OLS results to alternatives. Including fixed effects for continents had virtually no effect on the index coefficient or its standard error. Using White's method to estimate the standard errors reduced the t-statistic for the index to 2.87. Estimation by minimum absolute deviations did cause a substantial change, lowering the ownership index coefficient to .0028 with a t-statistic of 1.49.

We also estimated models that include dummy variables for latitude bands to proxy environmental attributes. They were not included in the final specification because they correspond closely to high versus low income countries, and hence partially capture stability effects. When latitude bands are included, the stability coefficient drops by 40 percent and the t-statistic is reduced to about 2.1. If the model with latitude terms is re-estimated on a sample that excludes high income countries, however, the index coefficient and t-statistic rise to roughly the levels shown in Table 6.

3.6 Does a Single Political Index Apply to All Investments?

Our approach assumes that the generic ownership security index computed for economy-wide investment applies without modification to natural resource investments. Specific forms of capital differ in their mobility and durability, however, and this might cause differences in the political factors that affect them. To test this assumption, each natural

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[46] When the same model was estimated for countries with primarily open forest, neither the initial forest stock nor the political index were significant, and the overall regression was not statistically significant. The model may not work well for open forest lands, because the principal crop is forage for animals rather than forest biomass.

resource model was re-estimated in a form that includes the individual political variables as separate arguments in place of the index. We then tested the hypothesis that the vector of political coefficients is proportional to the coefficient vector from the investment model, to reveal whether natural resource investments are somehow 'special.' Results are discussed for deforestation, oil drilling, and oil production in that order.[47]

Our analysis of deforestation is based on a cross section of forest stock changes for 1980-1985. The political variables used in our test are 1983 values of regime dummies, country specific frequencies of instability events averaged over the full sample period (1950-1988), and 1980-1985 country averages of instability events in place of current events and one year lags. The null hypothesis could not be rejected in this case, so the generic political index represents forest cover changes adequately.

When an analogous procedure was followed for oil drilling, the null hypothesis was rejected, so the coefficient vectors are significantly different in this case. The differences are in the <u>degree</u> to which specific political factors matter, however, rather than differences in the signs or identity of significant terms. All of the significant political factors in the drilling model have the same sign as in the investment model. Compared to overall investment, however, drilling assigns a significantly greater negative weight to: monarchy, current purges and assassinations, average frequencies of revolutions, average frequencies of constitutional changes away from parliamentary or non-parliamentary democracy, and constitutional changes within the non-democratic regime. Constitutional changes away from non-democratic toward democratic regimes favor drilling more than ordinary capital investment.

Though statistically significant, these differences are not large. To demonstrate this a new stability index was formed using the political coefficients from the drilling model. The simple correlation between the two stability indexes is .7432, so they track one another fairly closely despite being estimated on much different samples of countries and years. Also,

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[47] These empirical results are not reported here to save space, but are available on request.

inserting the new stability index into the drilling model in place of the original one improved the model's adjusted R^2 only slightly, from .5179 to .5280. For drilling, then, the generic index works reasonably well.

The results obtained for oil production are more complex. First, the hypothesis of proportional political coefficients is clearly rejected. The effects of political regimes are qualitatively similar to those for ordinary investment: production is slow under monarchy and the 'other' regime category and fast under parliamentary and non-parliamentary democracy.[48]

Surprisingly, the effects of political instability events on oil production consistently run in the opposite direction--production is relatively rapid when such events are prevalent. Compared to the results for general investment, this is a consistent change in sign. The average frequencies of political assassinations and guerrilla warfare are both significant and positively related to production. Among the five significant constitutional change frequencies, a greater likelihood of change that moves a country away from democracy (R1 or R2) spurs production, while a greater likelihood of change toward democracy from the non-democratic regime slows production.[49]

Our modeling approach suggests the following interpretation, although alternative explanations clearly are possible. Oil production requires two kinds of capital, known oil reserves and oil producing equipment. Both are subject to expropriation risk, but the political factors that determine expropriation probabilities may differ for the two. The finding that oil extraction rates are higher in politically 'safe regimes,' such as parliamentary and non-parliamentary democracy, suggests that a country's 'political regime' is a good indicator of expropriation risk for oil production capital. Accordingly, countries with safe regimes should

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[48] The negative effect for monarchy may partially be due to an OPEC influence, since oil producing monarchies tend to be middle east OPEC members.

[49] The average frequency of purges is significant and negatively related to production, which is also the opposite of the sign obtained for the investment model. As explained earlier, this variable may act as a dummy that partially distinguishes Latin American from African countries.

have extensive capital bases to support rapid oil extraction. The finding that countries with higher frequencies of revolutions, political assassinations, and constitutional changes extract more rapidly suggests that these 'event frequencies' are good indicators of expropriation risk for reserves. Hence, such events should signal that expropriation of reserves is likely, causing producers to extract more rapidly.

The quantitative importance of these results was gauged by using the political coefficients from the production model to form another new ownership security index. The simple correlation between this index and the generic one is .5676, which is highly significant. Given this and the significant coefficient for the generic index in Table 6, the generic index clearly captures some important aspects of oil production decisions. It does not tell the whole story, however. Re-estimating the oil production model with the new stability index increased both the adjusted R^2, from .2218 to .3992, and the sensitivity of production to a one standard deviation change in stability.

4. CONCLUSIONS

Our primary aim was to test the hypothesis that ordinary investment and natural resource use are affected by insecure ownership and to estimate the size of such effects. Our results indicate areas where the conventional wisdom regarding relationships among ownership risk, investment, and natural resource use needs to be revised or extended.

The empirical literature on capital investment has focused on two political variables as indicators of insecure ownership, the frequency of coups and revolutions (summed) and the frequency of political assassinations.[50] Our results demonstrate that the set of relevant political factors is much richer. A country's political regime and the frequency of constitutional changes that result in specific kinds of regime shifts appear to be more salient. The point estimates indicate that differences in regime alone can account for investment rate differences

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[50] See Barro (1991), Persson and Tabellini (1994), and Levine and Renelt (1992).

of as much as eight percent of GDP. As a rule, a greater chance of constitutional change that moves a country away from democracy reduces investment, and a change in the opposite direction increases it. Political effects are quantitatively important: a one standard deviation change in our index corresponds to a 4.3 percentage point change in the investment rate.

The finding that forest stocks are reduced by ownership risk adds to a growing body of evidence indicating that weak property rights are an important cause of deforestation.[51] The exploitation of one important non-renewable resource, petroleum, was shown to be highly sensitive to ownership risk, but the effect is complex. Investments in resource discovery are hampered by ownership risk, as expected, and the magnitude of the effect is surprisingly large. The effect of expropriation risk on production rates for resources already discovered was shown to be ambiguous at a theoretical level. Empirically, increased risk reduces extraction rates, apparently by hindering investments in capital equipment needed for extraction. This result agrees with a theoretical possibility shown by Farzin (1985), and to our knowledge provides the first empirical confirmation of this effect.

Finally, our results shed light on some of the factors that govern the relationship between resource use and levels of economic development. The adage that natural resources are used up rapidly in situations where ownership risk is high is supported for forest stocks, but soundly rejected for petroleum. In the latter case insecure ownership hinders resource extraction because it hinders investments, both in resource discovery and in the capital equipment needed for extraction. Regarding the relationship between resource stocks and levels of economic development, stocks of capital intensive resources should tend to remain largely unexploited in poor countries, because the lack of ownership that causes their poverty also hampers accumulation of capital needed for stock extraction. Making ownership more secure should cause income to rise by stimulating investment, and resource stocks to decline.

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[51] Examples are Southgate, Sierra, and Brown (1991), Alston, Libecap and Schneider (1996), Deacon (1994), and Lopez (1992).

The predicted result in this case is an inverse relationship between income and resource stocks. For resources requiring little capital for extraction, such as forests, incomes and stock levels should be positively correlated. Generalizing, the empirical relationship between natural resource use and the stage of economic development is likely to be resource specific, and to depend critically on the capital intensity of the resource extraction process.

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