Ownership Risk, Investment, and the Use of Natural Resources

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The effect of insecure ownership on ordinary investment and natural resource use is examined. Insecure ownership is postulated to depend on the type of government regime in power and the prevalence of political violence or instability. The political determinants of economywide investment are estimated from cross-country data, and the results are used to form an index of ownership security. When introduced into empirical models of natural resource use, this index has a significant and quantitatively important effect on the use of forests and petroleum. Contrary to conventional wisdom, ownership risk slows resource use in some circumstances. (*JEL* Q20, Q30, E22)

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, 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 overuse resource stocks due to free-access problems. The economic-growth literature points out that weak ownership forestalls the physical and human-capital investments needed for economic development. 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.[2]

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 relevant elasticities.[3] Second, the change in resource use that accompanies development seems to vary from resource to resource in ways that existing discussions do not capture.[4] There is much publicity about the way poorer nations, the "South," strip biomass from forests to obtain fuelwood and nutrients for farming, causing the destruction of natural forest habitats. For fossil fuels

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[1] Research on "environmental Kuznets curves," e.g., Namet Shafik and Sushenjit Bandyopadhyay (1992), Gene M. Grossman and Alan B. Krueger (1993), Maureen Cropper and Charles Griffiths (1994), and Thomas M. Selden and Daquing Song (1994), is relevant here.

[2] On property rights and growth, see Roger C. Kormendi and Philip G. Meguire (1985), Kevin B. Grier and Gordon Tullock (1989), Robert Barro (1991), Ross Levine and David Renelt (1992), and Torsten Persson and Guido Tabellini (1994). On property rights and resource use, see Graciela Chichilnisky (1994) and Ramon Lopez (1994). Resource use might also differ across countries because of differences in rates of time preference or rates of return. In a world with mobile capital, such differences would be arbitraged away, aside from adjustments for political risk. Our theoretical model takes this open-economy view and assumes that real interest rates adjusted for such risk are equal across countries.

[3] Some evidence is emerging, however; see Douglas Southgate et al. (1991), Lopez (1992), Deacon (1994), and Lee J. Alston et al. (1996).

[4] See Lopez (1994) for a model and World Resources Institute (WRI) (1994 Ch. 1) for evidence.

and minerals, however, extraction and consumption appear far more 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 natural 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 losing ownership causes the future return from maintaining the stock to be discounted heavily.[5] Clearing forests to obtain fuel or agricultural land is a labor-intensive extraction process that 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. Petroleum is a prime example; it requires a large outlay for exploration and production equipment before any extraction can begin.[6]

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 cross-country empirical work on investment and growth. Basically, we postulate that ownership risk is related to observable political attributes of countries and then use data on economywide 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 plugged into models of resource use for petroleum and forests to see if, and to what degree, ownership security matters.[7]

In general, we find highly significant and plausible relationships between political attributes of countries and their economywide investment rates, even after controlling for economic factors that modern growth theory suggests should be included. Regarding the paper's central objective, the ownership-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 can alter natural resource and environmental outcomes in developing countries. They cast doubt on the simple proposition that income growth,

[5] Ngo Van Long (1975) examines resource extraction under threat of nationalization.

[6] Similarly, a higher discount rate can slow resource extraction if the extraction process is sufficiently capital intensive. See Y. Hossein Farzin (1984) and Pierre Lasserre (1985).

[7] We have three reasons for basing the index on economywide investment data. First, we use the Robert Summers and Alan Heston (1995) 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.

from whatever source, is the key ingredient for transforming the use of environmental and natural resources.[8] Exogenous changes in income, e.g., resulting from North to South transfers, may have little effect unless they are accompanied by policies to solidify institutions of ownership. 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.

I. Theory

This section develops an economic model of investment and resource use that highlights the relationship between ownership risk and investment decisions. Specific models are developed for investments in produced capital, petroleum, and forests in an environment with ownership risk.

A. *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 in period $(t + 1)$, which means that the investor loses all claims to investment projects at the start of period $t + 1$. With probability $1 - \pi_t$, the investor's claims remain intact. For all investment decisions, we consider a small open economy that faces an exogenous world interest rate $r > 0$.

For all types of projects investors maximize current profits, PR_t, plus the discounted expected value of the project's future payoff. The expropriation event is a $0 - 1$ variable ξ_t that indicates whether or not period-t 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 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 ensures 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. The profit maximization problem can then be written as

$$(1) \quad V_t(\pi_t, \xi_t, \cdots) = \max\left\{ PR_t + \frac{1}{1+r} \times \int V_{t+1}(\pi_{t+1}, \xi_{t+1}, \cdots) \, dG(\pi_{t+1}, \xi_{t+1} | \pi_t, \xi_t) \right\}$$

for $\xi_t = 0$ and $V_t(\pi_t, \xi_t, \cdots) = 0$ for $\xi_t = 1$, where V_t represents the value function.[9] The

[8] This is a natural interpretation of recent empirical results on relationships between economic growth and the environment, e.g., Shafik and Bandyopadhyay (1992). To Shafik and Bandyopadhyay (1992 p. 1), alleviating poverty is "essential for environmental stewardship."

[9] Intuition suggests that if an 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 should be $(1 - \pi_t)/(1 + r)$ and the problem should be written as

$$(1') \qquad V_t^* = \max\left\{ PR_t + \frac{1 - \pi_t}{1 + r} \cdot E[V_{t+1}^*] \right\}$$

where V_t^* is the project value to the current owner and the expectation is conditional on no expropriation. While (1′) captures the intuition of our approach, the time-varying dots represent potential additional state variables that depend on the specific project. We now use this framework to examine investment decisions for produced capital, petroleum, and forests.

B. *Capital Investment*

We assume that output Y_t is produced from capital K_t and labor N_t according to the production function

$$Y_t = (N_t \cdot H_t)^{\alpha} \cdot K_t^{1-\alpha} \tag{2}$$

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 exogenous factors represented by $\mathbf{x_t}$, hence $g_H = g_H(\mathbf{x_t}, H_t)$. The variables $\mathbf{x_t}$ are assumed to follow a Markov process.[10]

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

$$K_{t+1} = K_t \cdot (1 - \delta) + I_t. \tag{3}$$

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 expropriated. The single period payoff is

$$\begin{aligned} PR_t = {} & (N_t \cdot H_t)^{\alpha} \cdot K_t^{1-\alpha} \\ & - [K_{t+1} - K_t \cdot (1 - \delta)] \\ & \times c(K_{t+1}/K_t - (1 - \delta)). \end{aligned} \tag{4}$$

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

$$\begin{aligned} & V(K_t, N_t, H_t, \mathbf{x_t}, \pi_t, \xi_t) \\ & = \max_{K_{t+1}} \Big\{ (N_t \cdot H_t)^{\alpha} \cdot K_t^{1-\alpha} \\ & \quad - [\mathrm{K}_{t+1} - \mathrm{K}_t \cdot (1 - \delta)] \\ & \quad \cdot \mathrm{c}(\mathrm{K}_{t+1}/\mathrm{K}_t - (1 - \delta)) \\ & \quad + \frac{1}{1+\mathrm{r}} \cdot \int \mathrm{V}(\mathrm{K}_{t+1}, \mathrm{N}_t \cdot (1 + \mathrm{n}), \end{aligned} \tag{5}$$

discount factor is technically inconvenient. Overcoming this difficulty is the main reason we cast the problem in the form (1), as a problem with a constant discount rate r and a separate state variable, ξ_t, that captures expropriation. Intuitively, a once-and-for-all expropriation is economically equivalent to an expropriation of all future profits. Since $\xi_{t+1} = 1$ is an absorbing state with zero profits, $V_{t+1}(\pi_{t+1}, 1, \cdots) = 0$. Equation (1) can therefore be written in terms of π_t and the conditional density of π_{t+1}, given $\xi_{t+1} = 0$:

$$\begin{aligned} & V_t^*(\pi_t, \xi_t, \cdots) \\ & = \max\Big\{ PR_t + \frac{1-\pi_t}{1+r} \cdot \int V_{t+1}(\pi_{t+1}, 0, \cdots) \\ & \qquad dG(\pi_{t+1} | \xi_{t+1} = 0, \pi_t, \xi_t) \Big\}. \end{aligned}$$

The integral is equivalent to $E[V_{t+1}^*]$, which shows that problems (1) and (1′) are equivalent, conditional on $\xi_t = 0$. Hence, problem (1) is consistent with the intuition that expropriation risk increases the effective discount rate. To avoid repeated discussion of the trivial $\xi_t = 1$ case, we assume throughout, and without further notice, that $\xi_t = 0$, i.e., that the investor initially owns the project.

[10] The empirical growth literature (citations below) suggests that productivity growth is affected by variables related to schooling and international trade. Although we are primarily interested in capital investment rather than growth, the determinants of productivity growth are relevant to the extent that productivity affects the returns to physical capital. Hence, we allow for a vector $\mathbf{x_t}$ of productivity determinants in the theoretical model and include appropriate controls in empirical analysis. The question of whether productivity growth is exogenous or endogenous to the growth process is not pursued in any detail, as our interest is focused on investments in physical capital. In an Appendix (available from the authors) we show that our final regression model, equation (8) below, is consistent with both exogenous and endogenous human-capital accumulation.

$$H_t \cdot (1 + g_H(\mathbf{x_t}, H_t)),\ \mathbf{x_{t+1}},\ \pi_{t+1},\ \xi_{t+1})$$

$$dG(\mathbf{x_{t+1}},\ \pi_{t+1},\ \xi_{t+1} | \mathbf{x_t},\ \pi_t,\ \xi_t) \Bigg\}.$$

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

$$(6) \qquad c(I_t/K_t) + I_t/K_t \cdot c'(I_t/K_t) = \frac{1}{1+r} \cdot \int V_K \, dG,$$

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 requires the marginal cost of K_t to equal the expected present value of its marginal return. An Appendix, available from the authors on request, shows that K^* is increasing in K_t (but less than one-for-one), increasing in H_t and in those elements of $\mathbf{x_t}$ 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. Accordingly, the dependent variable examined empirically is I_t/Y_t. Using the investment identity (3) and homogeneity of K^*, we can write

$$(7) \qquad (I_t/Y_t) = K^*(K_t/Y_t, N_t/Y_t, H_t, \mathbf{x_t}, \pi_t, \xi_t) - (1-\delta) \cdot K_t/Y_t.$$

This function is not ideal for empirical analysis, however, because the capital stock is not reported for many countries. To overcome this, we express K_t/Y_t as $(K_t/N_t) \cdot (N_t/Y_t)$, and then exploit the production function to replace K_t/N_t by $(Y_t/N_t)^{1/(1-\alpha)} \cdot H_t^{-\alpha/(1-\alpha)}$. With this substitution, the investment function can be written:

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

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 $\mathbf{x_t}$ that increase productivity growth and decreasing in π_t. The sign of its relationship to Y_t/N_t is ambiguous.

C. *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 H_t denote reserves that are undiscovered, or "hidden," at time t.[11] 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 $F(D) \to \Gamma$ as $D \to \infty$. Hidden reserves are then $H_t = \Gamma - F(D_t)$.[12] Known reserves that have not yet been extracted are denoted R_t. Known reserves are augmented by new discoveries, $F(D_{t+1}) - F(D_t)$, and reduced by production Z_t. Hence,

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

Oil production is assumed to require specialized capital, variable inputs such as goods and

[11] Some symbols are defined differently in different sections of the paper, e.g., H to denote human capital and hidden reserves. The meaning should be clear from the context.

[12] We do not distinguish between exploration and development wells in what follows, and treat cumulative reserve additions, $F(D_t)$, as a function of cumulative total drilling. In part this is pragmatic, since available data often fail to distinguish wells drilled for exploratory versus development reasons.

labor, and known reserves. The production function is taken to be Cobb-Douglas with constant returns to scale. Oil-extraction capital, K_t^0, includes pumps, processing equipment, and pipelines. It can only be used to produce oil and, hence, is distinct from the general capital stock modeled above.[13] 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 $\chi \cdot (Z_t/R_t)^\beta \cdot (K_t^0/R_t)^{-\upsilon}$, where $\beta > \upsilon > 0$ and χ is a function of production-function parameters and the wage rate.[14] 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.[15]

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

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

provided $\xi_t = 0$. The implied dynamic programming problem of form (1) is

$$(11)\quad V(R_t, H_t, K_t^0, p_t, \pi_t, \xi_t; \Gamma) = \max_{R_{t+1}, H_{t+1}, K_t^0} \Bigg\{ p_t \cdot (R_t - R_{t+1} + H_t - H_{t+1}) - \chi \cdot (K_t^0/R_t)^{-\upsilon} \times \frac{(R_t - R_{t+1} + H_t - H_{t+1})^{1+\beta}}{R_t^\beta} + (1 - \delta) \cdot K_t^0 - K_{t+1}^0 - c(F^{-1}(\Gamma - H_{t+1}) - F^{-1}(\Gamma - H_t)) + \frac{1}{1+r} \cdot \int V(R_{t+1}, H_{t+1}, K_{t+1}^0, p_{t+1}, \pi_{t+1}, \xi_{t+1}; \Gamma)\, dG(p_{t+1}, \pi_{t+1}, \xi_{t+1} | p_t, \pi_t, \xi_t) \Bigg\}.$$

Notice that (9) was used to eliminate Z_t, the rate of production, from (10). It is instructive to divide this optimization problem into a problem of oil production with given known reserves R and a problem of optimal oil drilling that determines optimal reserves.

The optimal production decision equates the price of oil to the marginal production cost plus the marginal opportunity cost of forgone reserves. In the current period, when production capital and reserves are given, production cost is a decreasing function of the capital-to-reserves ratio K_t^0/R_t. For future periods, when capital can be adjusted, linear homogeneity of

[13] To be consistent with this approach, we should subtract out oil investments in the empirical analysis of general capital investment below. We do not have data on oil capital, however, and suspect that the amount of truly specific capital is small in most countries. (In the sensitivity analysis reported below we find that the estimated ownership-risk index barely changes when we exclude oil producers, suggesting that our inability to subtract oil investments from general investment is empirically unimportant.) Oil capital is important for our theoretical development even if the stock is small, because the qualitative links between ownership risk and oil production depend on the existence of such capital.

[14] The cost function is derived in the Appendix.

[15] Empirically, we found that the real oil price exhibits a first-order autocorrelation coefficient near unity but no higher-order serial dependence. A random walk for oil prices is not problematic in our model provided the discount rate is strictly positive.

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 for the optimal ratio of production to reserves, $z_t = Z_t/R_t$, and for the optimal ratio of oil capital to reserves, $k^0_{t+1} = K^0_{t+1}/R_{t+1}$. The solution is characterized by the following first-order conditions,

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

$$\text{(12b)} \quad 1 = \frac{1}{1+r} \cdot \int V_K \, dG.$$

Condition (12a) says that the current net revenue from pumping and selling a unit of the reserve should just equal the expected present value of future profits from leaving it in the ground. Condition (12b) says that the marginal cost of oil-extraction capital (unity) 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; higher ownership risk reduces the expected payoff from oil 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. Ownership risk reduces the value of leaving reserves in the ground, hence z_t is increasing in π_t. 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

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

This reduced-form equation, with oil production expressed as a function of oil prices and ownership risk, is 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. Intuitively, this indeterminacy results from the fact that ownership risk has two opposing effects. First, ownership risk tends to increase production because firms rationally try to extract and sell reserves before expropriation. Ownership risk also reduces investment in oil capital, however, which raises extraction cost and slows extraction in subsequent periods. The latter effect will tend to dominate if extraction is highly capital intensive.[17]

Optimal drilling, the second part of the firm's 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, H_{t+1}, and the geologic

[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] See Farzin (1984) and Lasserre (1985).

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

$$(12c)\quad p_t - \chi \cdot (1 + \beta) \times \left(\frac{K_t^0}{R_t}\right)^{-v} \cdot \left(\frac{Z_t}{R_t}\right)^{\beta} + \frac{\partial c}{\partial H_{t+1}} = \frac{1}{1+r} \cdot \int V_H \, dG.$$

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 reserves 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 $(\Gamma - F(D_t))$, and the geologic parameter Γ. Accordingly, we write

$$(14)\quad \Delta D_{t+1} = D(p_t, \pi_t, \Gamma, F(D_t)).$$

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, $\Gamma - F(D_t)$, 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 of 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.

D. *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 I, subsection A. For expositional ease, forest harvesters are viewed as profit-maximizing firms who sell forest outputs at a given price. We argue below that the determinants our model identifies also apply 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

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

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 $\partial^2 F_{t+1}/\partial F_t^2 \cdot \bar{F} = (F_t/\bar{F}) \cdot g'' + 2g' < 0$.

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 with constant returns and that labor and produced capital enter with the same relative 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 $\beta > 0$.[18]

While standing, a forest occupies land that has alternative uses, principally agriculture, and conversion of forest land to subsistence farming is 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

[18] The derivation is in the Appendix.

determined by factors that determine the demand for agricultural land.[19]

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

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

where p_t^F denotes the price of harvested biomass in terms of the consumption good. In the context of ownership 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 (1),

$$(17) \quad V(\pi_t, \xi_t, F_t, p_t^F; \bar{F})$$

$$= \max_{F_{t+1}} \Bigg\{ p_t^F \cdot (F_t + F_t \cdot g(F_t/\bar{F}) - F_{t+1}) - c \cdot \frac{(F_t + F_t \cdot g(F_t/\bar{F}) - F_{t+1})^{1+\beta}}{F_t^{\beta}} + \frac{1}{1+r} \cdot \int V(p_{t+1}^F, F_t, \bar{F}, \pi_{t+1}, \xi_{t+1}) \, dG(p_{t+1}^F, \pi_{t+1}, \xi_{t+1} | p_t^F, \pi_t, \xi_t) \Bigg\}.$$

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

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

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_t^F. The proportionate change in forest stock, $(F_{t+1} - F_t)/F_t$, can be written

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

It is decreasing in π_t, p_t^F, and F_t, and increasing in $\bar{F}$. Equation (19) is the basis for our empirical analysis. In contrast to oil, the theory implies that an increase in ownership risk will unambiguously reduce the resource stock. This is due to our assumption that forest harvesting is no more capital intensive than generalized output.

In most developing countries forest biomass is used mainly for fuelwood and nutrients for shifting cultivation, not for commercial timber. We argue that the forest cover determinants identified by the model still apply, however. Intuitively, the initial and maximum forest cover, F_t and $\bar{F}$, are clearly relevant, as is the unit value of biomass, p_t^F. Regarding π_t, both fuelwood gathering and shifting cultivation use standing biomass as a capital-type input in the production of harvestable biomass. Increasing π_t lowers the incentive to maintain forest capital, which reduces the stock.[20] We interpret ownership risk broadly, to include the prospect of all events that might abridge the claims of a current decision maker, whether an individual, family, or village, to the returns obtained from a forest in future periods. In regions where forests are treated as communal or quasi-open access resources by local populations, ownership risk might best refer to insecure customary claims.

II. Estimation

The first empirical task is to estimate an economywide investment function that highlights the role of political factors related to expropriation risk. An ownership-risk index is then formed from the estimated investment model and plugged into models of oil explora-

[19] A more detailed treatment of land conversion would require modeling cleared land as a separate state variable, complicating the analysis significantly. We expect that ownership security would enter the resulting empirical model in essentially the same way.

[20] The effect of insecure ownership on forest use is qualitatively the same if forests are owned by families, clans, or villages rather than profit-maximizing firms.

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).

tion, oil production, and forest stocks. Cross-country data are used in estimation, and the exact samples used are described later.

A. *Political Attributes Examined*

We expect an investor's risk in a given country to be related to the country's 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 too weak to control activity in the countryside. As potential indicators of political instability, we examine: major constitutional changes, revolutions, political assassinations, purges, and guerrilla warfare.[21] Cross-country data on these events for all sovereign states are taken from Arthur S. Banks (1990) for the period 1950–1989. Table 1 explains how these events are defined. Table 2 gives summary statistics for the sample used to estimate the investment model.[22]

TABLE 2—SUMMARY STATISTICS FOR THE INVESTMENT MODEL

	Mean	Standard deviation
Political event frequencies		
Revolutions	0.1424	0.3495
Constitutional changes	0.0852	0.2792
Political assassinations	0.0953	0.2937
Purges	0.1049	0.3064
Guerrilla warfare	0.1875	0.3904
Economic variables		
Investment/output (percent)	16.59	9.12
Real output per worker (1990$)	8,879	8,366
Secondary-school enrollment	0.0288	0.0244
Openness (percent)	56.65	38.74

Instability aside, the type of government regime in power might also matter to investors. Mancur Olson, Jr. (1993 p. 572) points out that an investor's property claim in a country ruled by an individual or clique 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 eliminating a single person or small cadre may alter the country's entire system of property claims. Accordingly, we hypothesize that the average citizen's ownership security tends to be weak in countries ruled by individuals and dominant elites, and strong in countries ruled by impersonal laws and institutions. To capture

[21] Since our investment data include public investment, we should note that government instability may 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. Government investment is attractive to the group in power only if the conduit is expected to remain stable so that the party that promotes a public investment is assured of receiving the ultimate reward. James K. Boyce (1993 pp. 226, 233) provides supporting evidence from forest use in the Philippines. It would be attractive to test this hypothesis by including the degree of government ownership of capital or natural resources in empirical models, but available data are insufficient.

[22] Dummy variables, defined to equal one if at least one such event occurred in a given country and year, represent events. 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 coups and revolutions as an instability indicator amounts to assigning successful revolutions twice the impact of unsuccessful revolutions.

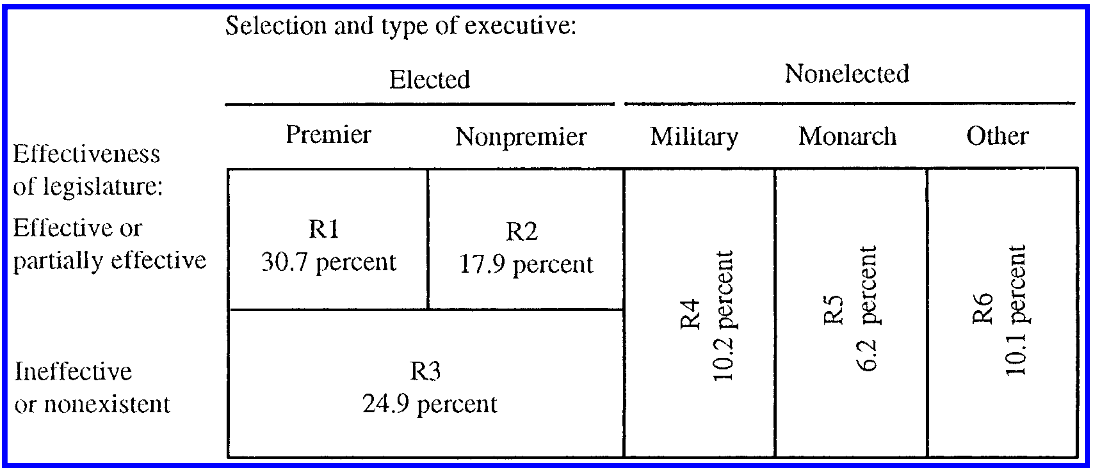

FIGURE 1. DEFINITIONS OF REGIMES

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

such effects we define political regimes and assign one regime to each country in each year.

We define regimes using information from Banks (1990) 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 nonelective,) and the existence or effectiveness of the legislature (effective, partially effective, ineffective, and nonexistent).[23] Figure 1 describes our regime 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. Nonparliamentary democracies are largely presidential systems. Regime type 6 is a mixture of countries in anarchy, protectorates, and other forms of government.[24]

B. *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 ($\mathbf{x_t}$), and the expropriation probability (π_t). The data set contains annual observations on 125 countries, drawn from the period 1955–1988.[25] Data on I_t/Y_t and Y_t/N_t were taken from the 1996 version of the Penn World Table (Summers and Heston, 1995). Communist countries were excluded because their investment data seemed unreliable. I_t/Y_t is measured as total investment, public plus private, as a percent of GDP.[26]

[23] 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 taxing and spending authority 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.

[24] These regime definitions correspond roughly to degrees of "inclusiveness," as that term is used by Martin C. McGuire and Olson (1996), with the democratic regimes (R1 and R2) being more inclusive than the nondemocratic regimes (R3–R6).

[25] The number of countries covered increases over the sample period.

[26] One might expect ownership risk to affect private investment more severely than public investment. If so, our empirical results might well be stronger if only private

Our specification is motivated by and draws on recent work in the cross-country growth literature. There is a vast literature on the empirical determinants of GDP growth and total factor productivity growth. For recent surveys, see Robert Barro and Xavier Sala-i-Martin (1995 Ch. 12), Sebastian Edwards (1997), and Jonathan Temple (1999). Only a few papers explicitly address the determinants of capital investment, however, notably Barro and Sala-i-Martin (1995 Ch. 12.5) and Jeffrey D. Sachs and Andrew Warner (1995 Table 12). The theoretical analysis of Section II suggests that the determinants of capital investment should include the determinants of productivity growth.[27] Hence, we follow the growth literature and consider measures of schooling and openness as control variables. The resulting investment models are similar to those in Barro and Sala-i-Martin (1995) and Sachs and Warner (1995).

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, obtained from Banks (1990).

The cross-country growth literature suggests that productivity growth is significantly correlated with measures of openness (see, e.g., Barro and Sala-i-Martin, 1995; Sachs and Warner, 1995; Edwards, 1997). Many empirical indicators for openness are, however, essentially policy indicators. This is unfortunate for our purposes, because if the political attributes that we focus on are correlated with policy indicators for openness, the inclusion of such indicators might bias our results. Moreover, most indicators are not available for a sufficient number of countries and periods.

Conceptually, openness is supposed to raise productivity growth because interaction with more developed countries may enhance learning. This motivation suggests that the scale of a country's international trade is important for growth, regardless of whether it is due to favorable trade policy, a small country size, or comparative advantage in tradable-goods industries. If we interpret trade policy as determined endogenously, in part by the political attributes under study, an ideal control for variations in productivity growth due to learning effects would be an openness indicator that excludes policy effects. Hence, a crude indicator of trade, such as Summers and Heston's sum of exports and imports divided by GDP should, for our purposes, be preferable to the indexes used in more recent growth studies (e.g., Edwards, 1997). Recognizing that this view might be controversial, and since the growth literature has not agreed which, if any, indicator for openness is best, we examine several alternatives and show robustness—the choice of control variables has only minor effects on our results. Our benchmark specification includes only the Summers-Heston indicator (exports and imports divided by GDP). In alternative specifications, we either (a) exclude the Summers-Heston indicator or (b) replace it by the Sachs-Warner index, a policy-oriented index that is available for a relatively large sample. Summary statistics for all economic variables in the benchmark model are shown in Table 2.

Other considerations dictate inclusion of two additional variables. First, we expect investment to fluctuate over the business cycle for reasons not spelled out in the model, so the average unemployment rate in the G-7 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.

Our treatment of political variables in the investment model warrants a detailed discussion. 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-specific ownership risk that is best

investment were examined. The Penn World Table does not provide private-investment data for the vast majority of low-income countries, however. One might also argue that ownership risk is more salient for foreign investors than domestic investors. Available cross-country series do not report foreign-owned versus domestically owned investment separately, however.

[27] Again, unlike most of the cross-country growth literature, we are not primarily interested in productivity growth per se, and we merely try to avoid omitted variables problems by including a list of productivity determinants that are likely to affect capital investment.

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 country-specific average frequency of each political event 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 may do little damage in a dictatorship where property claims are already weak. Interactions between regime dummies and event variables were examined to allow for this.

Our treatment of constitutional change is more complex. Banks (1990 p. 17) records only *major* constitutional changes, e.g., "adoption of a new constitution that significantly alters the prerogatives of the various branches of government," and excludes amendments that follow constitutional rules. Such constitutional changes often coincide with a change in the type of political regime. One 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 combination of regimes in force 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 country-specific average frequency, plus dummies for current and lagged changes, for each of these nine constitutional-change variables.

We examined several alternative specifications and estimation methods for the investment model. The ownership-risk index, our sole reason for estimating this model, was robust to these changes, however. Hence we focus our discussion on the ordinary least-squares (OLS) results for expositional simplicity, and comment later on the results obtained from the variants we examined.

OLS estimates of the investment model are reported in Table 3. To avoid simultaneity problems, we used five-year lags rather than contemporaneous values for output per worker, secondary-school enrollment, and openness. Each of the economic variables suggested by growth theory is highly significant and of expected sign. Elasticities of investment with respect to these variables evaluated at sample means are 0.12 for real output per worker, 0.11 for secondary schooling, and 0.17 for openness.

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.[31]

[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. As explained shortly, an alternative specification in which perceived risk only depends on the frequency of observed events up to the current period produced very similar results.

[29] For example, one such variable equals one for a given country in year t if the country began year t in regime 1, ended it in regime 2, and a constitutional change occurred during year t.

[30] A priori regimes 3 through 6 appear less democratic than regimes 1 and 2. They were aggregated because they have similar investment rates after controlling for nonpolitical factors.

[31] 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 are ordered as one might expect: 8.5 for parliamentary democracy, 5.9 for nonparliamentary democ-

TABLE 3—INVESTMENT MODEL

	Investment/output	
Dependent variable	Coefficient	t-statistic
Economic variables		
Output per worker	0.00023	(11.95)
Secondary-school enrollment	63.42	(10.34)
Openness	0.0501	(14.48)
G-7 unemployment rate	−0.6301	(−9.23)
OPEC	4.3234	(9.51)
Regimes		
R1 Parliamentary democracy	8.3615	(15.53)
R2 Nonparliamentary democracy	4.5404	(8.03)
R3 Strong executive	4.8718	(9.45)
R4 Military dictatorship	4.1374	(6.89)
R6 Other	4.4279	(7.55)
Average frequencies of instability events		
Revolutions	−0.1499	(−10.99)
Political assassinations	0.0322	(1.89)
Purges	0.1351	(9.05)
Guerrilla warfare	0.0082	(0.84)
Constitutional change, R1R1	−0.7743	(−8.59)
Constitutional change, R1R2	−0.8073	(−4.68)
Constitutional change, R1RA	0.0472	(0.41)
Constitutional change, R2R1	1.4445	(2.92)
Constitutional change, R2R2	−0.0315	(−0.46)
Constitutional change, R2RA	−0.6451	(−4.51)
Constitutional change, RAR1	−0.1766	(−0.64)
Constitutional change, RAR2	0.9962	(5.20)
Constitutional change, RARA	−0.2089	(−9.83)
Current and lagged instability events		
Revolutions (t)	0.1508	(0.39)
Revolutions ($t-1$)	−0.2922	(−0.76)
Political assassinations (t)	−0.8012	(−1.93)
Political assassinations ($t-1$)	−0.7452	(−1.79)
Purges (t)	−0.4112	(−1.03)
Purges ($t-1$)	−0.2744	(−0.71)
Guerrilla warfare (t)	0.5581	(1.54)
Guerrilla warfare ($t-1$)	0.5843	(1.62)
Constitutional change, R1R1 (t)	−1.0856	(−0.67)
Constitutional change, R1R1 ($t-1$)	−2.3246	(−1.48)
Constitutional change, R1R2 (t)	−4.5868	(−1.80)
Constitutional change, R1R2 ($t-1$)	1.7952	(0.71)
Constitutional change, R1RA (t)	−3.2515	(−1.71)
Constitutional change, R1RA ($t-1$)	−0.4333	(−0.23)
Constitutional change, R2R1 (t)	0.3421	(0.06)
Constitutional change, R2R1 ($t-1$)	−4.7149	(−0.76)
Constitutional change, R2R2 (t)	0.7920	(0.58)
Constitutional change, R2R2 ($t-1$)	−0.7560	(−0.55)
Constitutional change, R2RA (t)	−0.6438	(−0.39)
Constitutional change, R2RA ($t-1$)	−0.5324	(−0.33)
Constitutional change, RAR1 (t)	3.4192	(0.90)
Constitutional change, RAR1 ($t-1$)	−1.6642	(−0.46)
Constitutional change, RAR2 (t)	−0.5887	(−0.25)
Constitutional change, RAR2 ($t-1$)	−1.7186	(−0.73)
Constitutional change, RARA (t)	−0.0989	(−0.19)
Constitutional change, RARA ($t-1$)	−0.0796	(0.16)
Constant	9.0637	(14.26)
N	3146	
R^2 adjusted	0.55	

Notes: 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 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 10-percent point increase in the annual probability of a revolution is to cut the investment rate by 1.5 percentage points. The anomalous positive sign for purges is discussed shortly. We confine our discussion of constitutional changes to the statistically significant terms. Here, the signs of coefficients coincide with expectations. A constitutional change that does not change the form of regime tends to reduce investment. When a constitutional change coincides with a change in the form of regime, the effect is: to reduce investment if the change is away from parliamentary democracy, to reduce investment if the change is to the nondemocratic regime, and to raise investment if the change is away from the nondemocratic regime. In a nonparliamentary democracy (R2), a higher probability of switching to the parliamentary regime raises investment. These results agree with the interpretation that ownership is most secure under parliamentary democracy and least secure under nondemocracy, with nonparliamentary democracy in between.

Current and lagged instability events 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.[32]

Regarding the puzzling effect of purges, our analysis of event-regime interactions revealed a possible explanation. The positive association between purges and investment occurs primarily in regime 2, nonparliamentary democracy. A check for 1960, 1970, and 1980 shows that, aside from a few high-income countries, regime 2 is dominated by two groups of less developed nations, one African and one Latin American. The 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. Purges may therefore be capturing the influence of an omitted political attribute that effectively distinguishes some African from some Latin American nations, rather than anything causal.[33]

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.[34] This variable, termed the "benchmark index," is used for π_t in models of oil exploration, oil production, and forestry. In the overall sample, the benchmark index has a mean of 12.55 and a standard deviation of 4.22. The cross-country average declined steadily between 1955 and 1977, due mainly to the formation of new, relatively risky, nations, and remained roughly constant thereafter. Average risk for countries represented in the sample in all years was roughly constant.

Several alternatives to the benchmark specification in Table 3 were considered. Recall that our primary reason for estimating the investment equation is to derive an ownership-risk index. Hence, our basis for evaluating these variants is the effect they had on the index. We varied the treatment of openness in the model, first by dropping openness entirely and then by including the Sachs-Warner index described earlier. In both cases the resulting indexes were correlated with the benchmark index at 0.97 or better. Next, we tried different lag lengths for output per worker, secondary enrollment, and openness, and found that this choice makes little difference. Using one-year versus five-year lags of these variables yielded indexes that have a simple correlation of 0.997. We also tried in-

racy, 4.2 for strong executive, 2.8 for military dictatorship, and 2.7 for other. The hypothesis of equality is rejected for each pair of regime coefficients, except military dictatorship and other.

[32] We examined the possibility of regime-event interactions, e.g., the investment effect of revolutions, constitutional changes, etc., might be different for a country in regime 1 versus regime 3. These interactions turned out to be statistically insignificant, however.

[33] This interpretation is bolstered by results from country-specific regressions of the investment share on economic variables plus current and lagged purges. We estimated these to see 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 5 positive coefficients were significant.

[34] The index is available from the authors on request. It contains 3,146 observations and, hence, would be too unwieldy to reproduce here.

cluding a real interest-rate variable, a term our theoretical model assumed constant for analytical convenience. Its coefficient is significant and negative, but the resulting index is correlated with the benchmark index at the 0.999 level. Finally, we reestimated the ownership-risk index for a sample that excludes countries with oil production to eliminate any effects due to our inability to subtract oil investments from general investment. The resulting index was correlated with the benchmark at the 0.95 level.

We also tried alternatives to the pooled OLS estimation strategy and, again, based evaluations on the effects these alternatives had on the index. Correcting for within-country, first-order serial correlation yielded an ownership index that is correlated with the benchmark index at the 0.97 level. Including fixed or random effects for continents yielded indexes correlated with the benchmark index at the 0.97 level or higher. Because the average event frequencies are fixed by country, and the regime dummies are nearly fixed by country, estimation with country-level fixed effects is not possible. Estimating the investment model with random effects for countries produced an index that is correlated with the benchmark index at 0.87. Because the OLS results appear robust, we rely on them for simplicity in what follows.

While the index appears robust, one might well ask if it really measures what we intend it to measure: ownership risk. With this motivation we compared it to another measure of ownership or political risk, in terms of its ability to explain investment behavior. We obtained data on investment risk from the firm Business Environment Risk Intelligence, Inc. (BERI). BERI reports overall business-risk scores for a large number of countries in years after 1970. We reestimated the investment model twice, constraining the samples to be the same in both. The nonpolitical terms were kept in both runs, but the political variables were replaced, alternately, with the benchmark index and the BERI index. Naturally, the risk coefficients were both highly significant (t-statistics of 14.4 for the benchmark and 10.4 for BERI). The benchmark index actually explained a higher proportion of the variance in investment than BERI (R^2 of 0.50 for the benchmark versus 0.44 for BERI). The implied effect on investment of changing the index by one standard deviation was almost exactly the same for both, 3.38 percent for the benchmark and 3.30 percent for BERI. Overall, the benchmark index appears to measure what we intend it to measure.

C. *Oil Discovery*

Our analysis of oil discovery is based on (14), which expresses the drilling rate as a function of p_t, π_t, $F(D_t)$, and Γ. The last two terms, cumulative discoveries and the initial geologic abundance of the resource, capture the positive effect of favorable geologic conditions on oil drilling—more drilling occurs in countries where oil is abundant. We infer geologic conditions from an auxiliary model of the drilling success rate, the fraction of wells that strike oil, as explained shortly.

The drilling success rate in a country depends on geologic abundance and economic factors. The latter 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-input prices are captured by yearly fixed effects since they tend to vary over time but not across countries. Ownership risk is relevant for the same reason price and cost are; hence the index is included. With these controls for economic variables, geologic abundance is treated as a country-specific fixed effect. This success-rate model was estimated by OLS with yearly and country fixed effects, using data for 27 countries over 1957–1988. The country fixed effects were then retrieved for use as an indicator of geologic abundance.[35]

The drilling model can now be estimated directly. The dependent variable is total wells (exploration plus production) drilled per year.[36]

[35] 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. The sample includes observations for Algeria, Argentina, Austria, Bahrain, Bolivia, Canada, Chile, Colombia, Ecuador, France, Germany (Federal Republic), Guatemala, Indonesia, Iran, Iraq, Japan, Kuwait, Mexico, Morocco, Myanmar, The Netherlands, Oman, Pakistan, Peru, Saudi Arabia, Syria, and Turkey. The number of available observations varies by country.

[36] Exploration and development drilling are economically similar in that both represent "up-front" outlays required to make subsequent production possible. While it might be interesting to examine exploratory versus

The regressors include the ownership-security index, price, and geologic abundance. Two additional independent variables were included to capture differences in oil quality and differences in drilling and production costs, the average gravity of a country's crude oil, and the average depth of its reserves. Data sources for drilling, gravity, and depth, plus further details on the series used, are provided in Table 4, which reports drilling results. The 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, a time trend was included to capture possible changes in input prices and technology. We expect OPEC membership, price changes, etc., to have roughly the same proportionate effect on drilling in different countries and years. For this reason we express drilling rates and all independent variables except the security index in natural logs.[37]

Table 4 reports OLS estimates of the drilling model. The ownership index is highly significant and positive, so drilling is more extensive in less risky countries. The predicted change in drilling from a one-standard-deviation change in the index is 68 percent, so the effect is large. Price, geologic abundance, and land area are also significant and of expected sign. The OPEC dummy is of expected sign and plausible magnitude.

We examined the robustness of the pooled OLS estimates to alternative specifications and estimation strategies and here summarize the results obtained for the variable of central interest, ownership security. First, it might seem natural to include cumulative production plus current reserves as a right-hand-side variable to measure cumulative discoveries, since the model in (14) indicated its inclusion. When we tried this, the ownership-security coefficient increased to 0.17 and it became more highly significant. We chose not to report these results because including the new variable raises econometric problems and the cumulative discoveries variable itself was not highly significant.[38] Including random effects for continents had no effect; continent fixed effects reduced the ownership coefficient by about one-third but it remained highly significant (t-statistic of 5.4). Including random effects for countries reduced the coefficient for the index by about half, but again it remained highly significant.[39] We found that the OLS residuals exhibit first-order serial correlation. Correcting for it reduced the index coefficient by about half, but it remained highly significant.[40]

TABLE 4—DRILLING MODEL

	Log(wells/year)	
Dependent variable	Coefficient	t-statistic
Ownership security	0.1377	(8.82)
Geologic abundance (fixed effect)	5.2052	(11.74)
Log(price)	0.6380	(6.36)
OPEC 1974–1985	−0.4594	(−2.56)
Log(API gravity)	−1.4822	(−5.70)
Log(depth)	−1.0770	(−7.53)
Log(land area)	0.7585	(21.30)
Year	−0.0226	(2.95)
Constant	50.7324	(3.41)
N	632	
R^2 adjusted	0.54	

Notes: Data sources are *Oil and Gas Journal Energy Database* (1993) for drilling rates and *Oil and Gas Journal* (various issues) 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-ten-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 not vary widely over time. Average depth is recorded as the average depth of each country's onshore oil in 1970.

development drilling separately, available data do not separate the two for many countries.

[37] Entering the index in logs produced very similar results.

[38] The problems arise from the fact that the cumulative discoveries variable is logically correlated with current and past drilling, and is itself nonstationary.

[39] Including fixed effects for countries is not practicable since some of the model's physical variables are fixed within countries and the index itself is highly persistent.

[40] Three additional variants were examined. To test sensitivity to outliers, the model was estimated by minimum

We also explored the econometric implications of the fact that our ownership-security index is a generated regressor, calculated from estimated regression coefficients. Adrian Pagan (1984) demonstrates that OLS coefficients and standard errors for generated regressors are consistent under the null hypothesis that the coefficient is zero. Hence, the *t*-statistics in Table 4 can be used to test the hypothesis of no effect. The standard errors are inconsistent under different nulls, however. To obtain consistent standard-error estimates we reestimated the drilling model using a procedure similar to two-stage least squares. The ownership index was replaced by investment/GDP and the nonpolitical variables from the investment model.[41] Since the investment rate is endogenous, the model was then estimated by instrumental variables using the ownership index as an instrument for investment/GDP. Given the way the index is computed, the investment rate takes on the role of the ownership-security index. This actually reduced the estimated standard error for the index by 10 percent, reinforcing the finding that ownership security is a highly significant determinant of drilling.[42]

Finally, we examined alternatives to our benchmark ownership-security index. As explained earlier, we reestimated the investment model with a sample that excludes countries used in the oil-drilling model, and then predicted a security index for oil-drilling countries. The intent was to assuage any concern that our results might be an artifact of our inability to subtract oil capital from general investment when estimating the index. Using this index in the drilling model yielded a coefficient that is one-fourth lower than in Table 4, but is still highly significant (*t*-statistic of 6.41). Next, we substituted the BERI index for our benchmark index. The BERI coefficient was highly significant (*t*-statistic of 2.91), but the implied impact of a one-standard-deviation change was substantially smaller than for the benchmark.

D. *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. We also include the average depth and American Petroleum Institute (API) gravity of a country's crude oil, because they affect production costs and oil quality, as well as a time trend to account for changes in technology and input prices. 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. These quotas and the degree to which they were obeyed presumably varied from member to member. Accordingly, we define separate dummy variables for each OPEC member and set each equal to one for 1974–1985. As with drilling, the dependent variable and all independent variables except the security index and dummies were entered in natural logs.[43] The sample covers the same countries (except Guatemala) and general time period as the drilling model, though missing values cause the two sample sizes to differ slightly.

Table 5 reports OLS estimates of the

absolute deviations. It was also reestimated 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 10 percent.

[41] Recall that the ownership-security index is essentially the economywide investment rate minus the influence of nonpolitical variables that affect investment rates.

[42] The point estimate was somewhat reduced in the two-stage procedure as well, but the *t*-statistic was still over 5.0.

[43] 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 measured to physical reserves gives the appropriate model for the dependent variable we actually observe, but the ratio of measured to physical reserves should now appear as an independent variable. We expect this ratio to be a function of oil price and determinants of production cost, however. Since variables for price and cost factors are included as regressors, the empirical specification remains correct.

oil-production model. 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. A one-standard-deviation change in the index corresponds to a 28-percent change in production, so the effect is large. As expected, production is positively related to price and negatively related to depth. The OPEC dummies show significantly lower output rates for Iran, Iraq, and Saudi Arabia during 1974–1985; surprisingly, Ecuador's output is significantly higher.

Several alternatives to the pooled OLS approach were examined, with the following effects on the ownership-security coefficient. Including fixed or random effects for continents had essentially no effect. Introducing random effects for countries reduced the ownership security coefficient by about 40 percent and lowered the *t*-statistic to 2.38.[44] We found that the OLS residuals exhibited first-order serial correlation. Correcting for it reduced the index by about one-half, but it remained highly significant (*t*-statistic of 3.10). Finally, using the two-step procedure to obtain a consistent estimate of the index coefficient's standard error raised it by about 10 percent.[45]

We also reestimated the model with the alternative indexes described in the discussion of exploration. Using the index estimated from an investment model that excludes oil countries reduced the index coefficient by one-fourth, but the *t*-statistic remained high (6.7). Using the BERI index yielded a significant positive coefficient (*t*-statistic 5.12). The implied production increase from a one-standard-deviation change in the BERI index was 24 percent, versus 28 percent for the benchmark.

The index varies widely across countries but is relatively stable over time within countries.

TABLE 5—OIL-PRODUCTION MODEL

Dependent variable	Log(output/reserve) Coefficient	*t*-statistic
Ownership security	0.0647	(9.12)
Log(price)	0.1129	(2.01)
OPEC dummies (1974–1985)		
Algeria	−0.2370	(−1.20)
Ecuador	0.4542	(2.35)
Indonesia	−0.2124	(−1.11)
Iran	−0.7128	(−3.66)
Iraq	−0.9357	(−4.92)
Saudi Arabia	−0.8157	(−4.08)
Log(API gravity)	0.0375	(0.27)
Log(depth)	−0.1640	(−2.06)
Year	−0.0052	(−1.19)
Constant	7.5388	(0.88)
N	636	
R^2 adjusted	0.22	

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 1970's. 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. OPEC dummy coefficients could not be estimated for several members due to insufficient data.

Hence, we believe the pooled OLS coefficient primarily captures long-run effects, which is consistent with its positive sign. To get a better indication of short-run effects we estimated within country models that include the following regressors: the index, oil price, an OPEC dummy for 1974–1985 if an OPEC member, and a time trend. The number of annual observations was sufficient to do this for 25 countries and the index was significantly positive in four cases and significantly negative in three. The three negative coefficients, indicating faster production when risk is high, are for Iran, Iraq,

[44] Using country-fixed effects is not informative because the security index, reservoir depth, and API gravity tend not to vary much over time within countries.

[45] The point estimate fell by about one-half, but it remained highly significant (*t*-statistic of 3.89). We also examined the effect of: estimating by minimum absolute deviations to reduce the effect of outliers and using White's method to estimate standard errors, and including a real interest rate. The coefficient and its standard error never changed by more than 12 percent.

and Oman.[46] The ownership-security indexes for these three countries are very low on average and highly changeable relative to other countries. This may explain why their production responses to risk seem to be dominated by short-run effects.

E. *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.

We use data on the areal extent of forest cover as a measure of stocks, and examine data by country for two years, 1980 and 1985. We considered using biomass measures of forest harvests and stocks in estimation, but decided against this course because available data on harvested biomass seem unreliable, particularly for developing countries.[47] Forested acreage is admittedly an imperfect stock measure, principally because it mixes questions of biomass with questions of land use, but it seems the best available for our purpose.[48] One attraction is that the resulting dependent variable is "minus the deforestation rate," which is of policy interest.[49]

TABLE 6—FOREST-COVER MODEL

Dependent variable	Proportionate change in forested area: Coefficient	*t*-statistic
Ownership security	0.0089	(5.68)
Initial forest biomass	0.1105	(4.22)
Water resources/land area	0.3003	(0.54)
Coastline/land area	−0.0291	(−1.81)
Population density	0.0053	(0.87)
Constant	−0.2147	(−7.88)
N	62	
R^2 adjusted	0.42	

Notes: The sample excludes a country if its 1980 forest cover was less than 5 percent of land area or if "closed forests" account for less than one-half of its total forest cover. Closed forests have at least 25-percent tree cover and no continuous grass cover. Open forests include grasslands, with tree cover as sparse as 10 percent, such as savannah or veldt regions of Africa.

The functional form estimated is linear. The dependent variable is already expressed as a proportionate change, and since it can be positive or negative, taking logs is infeasible. The ownership-risk index was averaged by country over 1981–1985. Two variables capture environmental determinants of forest stocks—a country's annual internal renewable water resources and the length of its coastline—both scaled by land area. To reflect demand for agricultural land, we include 1980–1985 average population density. This variable also allows us to test the common claim that population pressure is the primary cause of deforestation. Data on forest-product prices are incomplete and tend to exclude developing countries, so no price variable is included.

Table 6 reports OLS estimates of the forest model. The ownership index indicates that more risky countries experience more rapid deforestation. A one-standard-deviation difference in the index is associated with a 3.54-percent difference in the five-year change in forest stock. This is almost three-fourths of the mean change in forest stocks for the sample, so the effect is

[46] Federal Republic of Germany, Mexico, Peru, and Turkey had significantly positive coefficients.

[47] Biomass measures of harvests do not include removals for shifting cultivation. Further, reported data on removals for charcoal and fuelwood are estimates based entirely on population densities, and their reliability is unknown. Shifting cultivation and fuelwood are major forest uses in developing countries.

[48] Robert Mendelsohn (1994) demonstrates that insecure ownership will favor conversion of forest land to other uses, which is consistent with our specification. Forest-product prices should, however, have opposing effects on biomass and forested land.

[49] The primary data source for forest cover is the United Nations Food and Agriculture Organization (FAO) 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. We considered data from the 1990 FAO forest assessment to be unreliable, because estimates for forest clearing are based on population change rather than direct observation, and thus, we did not use them. See Cropper and Griffiths (1994 p. 251).

large. 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 approaches significance. The sign of population density is unexpected, but the coefficient is not significant. Applying Pagan's (1984) two-step procedure for consistent standard-error estimates increased the standard error of the ownership-security coefficient by a factor of three, but the variable remains highly significant.[50]

Again, we examined alternative specifications. Including dummy variables for latitude bands to proxy additional environmental attributes reduced the ownership-index coefficient by one-fourth, but it remained highly significant.[51] Replacing the benchmark index with the BERI index, averaged over 1981–1985, reduced the number of observations to 33. The BERI coefficient was of anticipated sign, but significant only at the 12-percent level. We also estimated models with fixed and random effects for continents. This changed the benchmark-index coefficient by less than 10 percent and *t*-statistics remained above 4.0.

F. *Does the Ownership-Security Index Capture All Political Effects?*

Our primary concern was to find out whether the same political factors that determine ordinary investment, after controlling for relevant macroeconomic variables, also affect the use of natural resources. Implicitly, we tested this hypothesis simply by entering the political index in models of resource use, and we did find effects that are large and significant. A more restrictive hypothesis is that the two sets of factors are identical, i.e., that the ownership-security index estimated from the investment model captures all political influences on natural resource use. This might not be true, of course, because specific natural and produced assets differ in their mobility, durability, and other attributes, and this might cause differences in the political factors that affect them.

It is easy to test the restrictive hypothesis by entering the index plus all but one of the political variables as separate regressors in each resource model and testing the joint significance of the separate political variables. When we did this for the forestry model the null could not be rejected, so the index represents forest-stock changes adequately.[52] The hypothesis was rejected for oil drilling, but the improvement in explanatory power from entering the separate political terms was fairly modest (adjusted R^2 rose from 0.54 to 0.60). When the separate political variables were entered without the index, the identity and signs of significant political terms were similar to the investment model.[53]

For oil production, the restrictive hypothesis is soundly rejected. Adding the separate political terms increases the adjusted R^2 from 0.22 to 0.43. Interestingly, the political-regime effects generally run in the opposite direction from the political event frequencies—production tends to be rapid in democratic regimes, which are arguably safe, but it is also more rapid when

[50] The two-step procedure caused the ownership-security coefficient to increase by 25 percent. When the OLS model was estimated for countries with primarily open forest, neither the initial forest stock nor the political index were highly significant, and the overall regression was not statistically significant. The model presumably does not work well for open forests because the principal crop is forage for animals rather than forest biomass. Using White's method to estimate the standard errors reduced the *t*-statistic somewhat, but it remained above 4.6. Estimation by minimum absolute deviations lowered the ownership-index coefficient by about half, but it remained highly significant ($t = 2.3$).

[51] Latitude bands were not included in the final specification because they correspond closely to high- versus low-income countries, and hence partially capture stability effects. Estimating the model with latitude bands on a sample that excludes high-income countries yields an index coefficient and *t*-statistic roughly equal to levels in Table 6.

[52] The political variables entered in the forest model are the 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.

[53] The drilling equation assigns a significant negative weight to military dictatorships, average frequencies of revolutions, political assassinations, constitutional changes away from parliamentary democracy, and constitutional changes within the nondemocratic regime. Positive effects are associated with changes from nondemocracy to democracy and purges. A contrary result is a positive effect for changes from the nondemocratic regime to nonparliamentary democracy.

unfavorable constitutional changes are more frequent. Recall that our model predicts that the short- and long-run oil-production responses to ownership risk should be of different signs, and this fact may hold an explanation for this puzzling empirical result. We leave a more detailed examination of this possibility as a subject for future research.[54]

III. 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 about how ownership risk affects 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 summed frequency of coups and revolutions, and the frequency of political assassinations.[55] 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 of as much as 8 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. These 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.

Our results shed light on the relationship between resource use and security of ownership. 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. 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.[56] The exploitation of petroleum was found 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, possibly by hindering investments in capital equipment needed for extraction. Overall, insecure ownership slows the extraction of petroleum and presumably other capital-intensive resources as well.

The empirical results also help illuminate the relationship between resource stocks and levels of economic development. Stocks of capital-intensive resources should remain largely unexploited in poor countries, because the lack of ownership that causes indigenous poverty also hampers accumulation of capital needed for extraction. Making ownership more secure should cause income to rise by stimulating investment, and resource stocks to decline, so the predicted result in this case is an inverse relationship between income and resource stocks. For resources requiring little capital for extraction, income levels and resource stocks 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 resource extraction.

Finally, perhaps the most significant result is the sheer size of the estimated political effects. If these correlations truly reflect causation, the recent apparent trend toward democracy and

[54] The empirical result would be consistent with our model if political regime is a good indicator of expropriation risk for oil-production capital and event frequencies are a good indicator of expropriation risk for reserves. In this case a safe regime would give investors the confidence needed to accumulate the production capital and tend to increase production, particularly over the long run. More frequent instability events, however, would spur producers to draw down reserve stocks more rapidly.

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

[56] See Southgate et al. (1991), Lopez (1992), Deacon (1994), and Alston et al. (1996).

reduced political instability worldwide will have profound effects on investment and on the way natural resources are used.

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