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*Economic Instability and Aggregate Investment**

1. *Introduction*

A growing theoretical literature has focused attention on the impact of risk on investment and has suggested that the impact may be large. The reason is that most investment expenditures are at least in part irreversible—sunk costs that cannot be recovered if market conditions turn out to be worse than expected. In addition, firms usually have some leeway over the timing of their investments—they can delay committing resources until new information arrives. When investments are irreversible and can be delayed, they become very sensitive to uncertainty over future payoffs. For example, in a simple and fundamental model of irreversible investment, McDonald and Siegel (1986) demonstrated that moderate amounts of uncertainty consistent with many large industrial projects could more than double the required rate of return for investments.[1] Hence, there is reason to expect changing economic conditions that affect the perceived riskiness of future cash flows

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1. McDonald and Siegel assumed that the investment can be made instantaneously. The multiple grows even larger when the project takes several years to complete; see Majd and Pindyck (1987). In these models, there is *always* uncertainty over future payoffs. In earlier models by Bernanke (1983) and Cukierman (1980), the uncertainty is reduced over time, but there is again a value to waiting. Sunk costs affect *exit* decisions in a similar way; see, e.g., Dixit (1989).

to have a large impact on investment decisions—larger, perhaps, than a change in interest rates.

This theoretical literature and the insight it provides may help to explain why neoclassical investment theory has so far failed to provide good empirical models of investment behavior and has led to overly optimistic forecasts of the effectiveness of interest rate and tax policies in stimulating investment.[2] It may also help to explain why the actual investment behavior of firms differs from the received wisdom taught in business schools. Observers of business practice find that the "hurdle rates" that firms require for expected returns on projects are typically three or four times the cost of capital.[3] In other words, firms do not invest until price rises substantially above long-run average cost.

But most important for this paper, the irreversible investment literature suggests that if a goal of macroeconomic policy is to stimulate investment over the short to intermediate term, stability and credibility may be much more important than particular levels of tax rates or interest rates.[4] Put another way, this literature suggests that if uncertainty over the evolution of the economic environment is high, tax and related incentives may have to be very large to have any significant impact on investment spending.

If this view is correct, it implies that a major cost of political and economic instability may be its depressing effect on investment. This is likely to be particularly important for developing economies. For many LDCs, investment as a fraction of GDP has fallen during the 1980s, despite moderate growth. Yet the success of macroeconomic policy in these countries requires increases in private investment. This has created a sort of Catch-22 that makes the social value of investment higher than its private value. The reason is that if firms do not have confidence that macro policies will succeed and growth trajectories will be maintained, they are afraid to invest, but if they do not invest, macro policies

2. As an example of the difficulty that traditional theory has had in explaining the data, consider the model of Abel and Blanchard (1986). Their model is one of the most sophisticated attempts to explain investment in a q theory framework; it uses a carefully constructed measure for marginal rather than average q, incorporates delivery lags and costs of adjustment, and explicitly models expectations of future values of explanatory variables. But they conclude that "our data are not sympathetic to the basic restrictions imposed by the q theory, even extended to allow for simple delivery lags."
3. The hurdle rate appropriate for investments with systematic risk will exceed the riskless rate, but not by enough to justify the numbers used by many companies.
4. We take it as a given that an important goal of macroeconomic policy is to encourage investment, largely because of the importance of investment for economic growth. We will not attempt to survey the literature relating investment to growth, and instead only point to the recent study by Levine and Renelt (1992), who show that the share of investment in GDP seems to be the only "robust" correlate with growth rates.

are indeed doomed to fail. This would make it important to understand how investment depends on risk factors at least partly under government control, e.g., price, wage, and exchange rate stability, the threat of price controls or expropriation, and changes in trade regimes.

Our aim in this paper is to explore the empirical relevance of irreversibility and uncertainty for aggregate investment behavior. We will be particularly concerned with the relative experience of developing versus industrialized countries. Although there is considerable anecdotal evidence that firms make investment decisions in a way that is at least roughly consistent with the theory (e.g., the use of hurdle rates that are much larger than the opportunity cost of capital as predicted by the CAPM), there has been little in the way of tests of the theory. In addition, there have been few attempts to determine whether irreversibility and uncertainty matter for investment at the aggregate level.

There are two reasons for the paucity of empirical work on irreversible investment. First, although we know that irreversibility and uncertainty should raise the threshold (e.g., the expected rate of return on a project) required for a firm to invest, we can say very little about the effects of uncertainty on the firm's *long-run average* rate of investment or average capital stock without making restrictive functional or parametric assumptions.[5] The reasons for this will be discussed shortly, but it means that tests cannot be based on simple equilibrium relationships between rates of investment and measures of risk, whether for firms, industries, or countries. Second, although shocks to demand or cost, as well as changes in risk measures, do have implications for the dynamics of investment, there are serious problems of aggregation that make it difficult to construct and test models at the industry or country level. Some of these problems have been spelled out by Caballero (1991, 1992), and Bertola and Caballero (1990) show how one can derive a cross-sectional distribution for the gap between the actual and desired investment of individual firms and use it to construct a model for the aggregate dynamics of investment.

An alternative approach is to focus on the threshold that triggers investment and see whether it depends on measures of risk in ways that the theory predicts. This has the advantage that the relationship between the threshold and risk is much easier to pin down than the relationship between investment and risk. The disadvantage is that the threshold cannot be observed directly. This approach was used in a

5. Bertola (1989) and Bertola and Caballero (1990) obtain results for the firm's average capital stock by making such assumptions. Bertola, e.g., shows that irreversibility and uncertainty can lead to capital deepening in long-run equilibrium, even though the firm has a higher hurdle rate and initially invests less.

recent study by Caballero and Pindyck (1992) of U.S. manufacturing industries, and it will provide one of the means by which we gauge the impact of uncertainty in this paper.

In the next section, we briefly review the basic theory of irreversible investment, stressing the value of waiting and its determinants. In Section 3 we extend this discussion by summarizing a slightly modified version of the model developed in Caballero and Pindyck (1992), and clarifying its empirical implications. Section 4 lays out a framework for assessing the effects of uncertainty—as measured by the volatility of the marginal profitability of capital—on investment at the aggregate level, and describes our data set. Section 5 presents a set of regressions that help us gauge the importance of volatility for investment. It shows that decade-to-decade changes in volatility have a moderate effect on investment and that the effect is greater for developing than for industrialized countries. In Section 6 we ask whether traditional measures of economic and political instability can explain the volatility of the marginal profitability of capital. We find that only inflation seems to be clearly correlated with this volatility. Finally, Section 7 studies the relationship between inflation and investment in more detail through semi-reduced form investment equations estimated with annual data for 1960–1990 for six "high-inflation" developing countries, as well as for six OECD countries.

2. *Review of the Theory and Its Implications*

It is useful to begin by summarizing the basic intuition underlying the theory of irreversible investment under uncertainty, and some of the more important results from the literature. For a more detailed introduction to the theory, see Dixit (1992), Pindyck (1991), and Dixit and Pindyck (1993).

It is helpful to think of an irreversible investment opportunity as analogous to a financial call option. A call option gives the holder the right, for some specified amount of time, to pay an exercise price and in return receive an asset (e.g., a share of stock) that has some value. Exercising the option is irreversible; although the asset can be sold to another investor, one cannot retrieve the option or the money that was paid to exercise it. A firm with an investment opportunity can likewise spend money (the "exercise price") now or in the future, in return for an asset (e.g., a project) of some value. Again, the asset can be sold to another firm, but the investment is irreversible. As with the financial call option, this option to invest is valuable in part because its net payoff is a convex function of the future value of the asset obtained by investing, which is uncertain. And like the financial option, one must determine the optimal "exercise" rule.

This analogy raises another issue—how do firms obtain their investment opportunities in the first place? The short answer is through R&D and the development of technological know-how, ownership of land or other resources, or the development of reputation, market position, or scale. But this suggests that understanding investment behavior requires that we understand not just how firms exercise their investment opportunities, but also how they obtain those opportunities (in part by investing, e.g., in R&D). This second issue is complicated by the fact that it is dependent on market structure. In this paper we will largely circumvent this issue by assuming competitive markets with free entry, and we will focus instead on how investment options are exercised. However, the reader should keep in mind that in so doing, we are ignoring what may be an important part of the story.[6]

Once we view investment as the exercising of an option, it is easy to see how uncertainty affects timing. Once a firm irreversibly invests, it exercises, or "kills," its option to invest. It gives up the possibility of waiting for new information to arrive that might affect the desirability or timing of the expenditure; it cannot disinvest should market conditions change adversely. This lost option value is an opportunity cost that must be included as part of the cost of the investment. As a result, the simple NPV rule that forms the basis of neoclassical models, "Invest when the value of a unit of capital is at least as large as its purchase and installation cost," must be modified. The value of the unit must *exceed* the purchase and installation cost, by an amount equal to the value of keeping the investment option alive.

By how much must the simple NPV rule be modified? One way to answer this is by looking at the basic model of McDonald and Siegel (1986). They considered the following problem: At what point is it optimal to pay a sunk cost I in return for a project whose value is V, given that V evolves according to the following geometric Brownian motion:

$$dV = \alpha V dt + \sigma V dz, \qquad (1)$$

where dz is the increment of a Wiener process. Equation (1) implies that the current value of the project is known, but future values are lognormally distributed with a variance that grows linearly with the

6. For example, Lach and Schankerman (1989) show for firm level data, and Lach and Rob (1992) show for two-digit U.S. manufacturing data, that R&D expenditures Granger-cause investment in machinery and equipment, and not the other way around.

time horizon. Thus, although information arrives over time (the firm observes V changing), the future value of the project is *always* uncertain.

We want an investment rule that maximizes the value of investment opportunity, which we denote by $F(V)$. Because the payoff from investing at time t is $V_t - I$, we want to maximize:

$$F(V) = \max E[(V_T - I)e^{-\rho T}], \tag{2}$$

where T is the (unknown) future time that the investment is made, ρ is a discount rate, and the maximization is subject to Equation (1) for V. For this problem to make sense, we must also assume that $\alpha < \rho$; otherwise the firm would never invest, and $F(V)$ would become infinite. We will let δ denote the difference $\rho - \alpha$.

The solution to this problem is straightforward. (See Chapter 5 of Dixit and Pindyck [1993] for a detailed exposition.) The optimal investment rule takes the form of a critical value V^* such that it is optimal to invest once $V \geq V^*$. The value of the investment opportunity (assuming the firm indeed invests only when V reaches V^*) is

$$F(V) = aV^{\beta}, \tag{3}$$

where β is given by:[7]

$$\beta = \frac{1}{2} - (\rho - \delta)/\sigma^2 + \sqrt{\left[(\rho - \delta)/\sigma^2 - \frac{1}{2}\right]^2 + 2\rho/\sigma^2} > 1. \tag{4}$$

The constant a and the critical value V^* are in turn given by:

$$V^* = \frac{\beta}{\beta - 1} I, \tag{5}$$

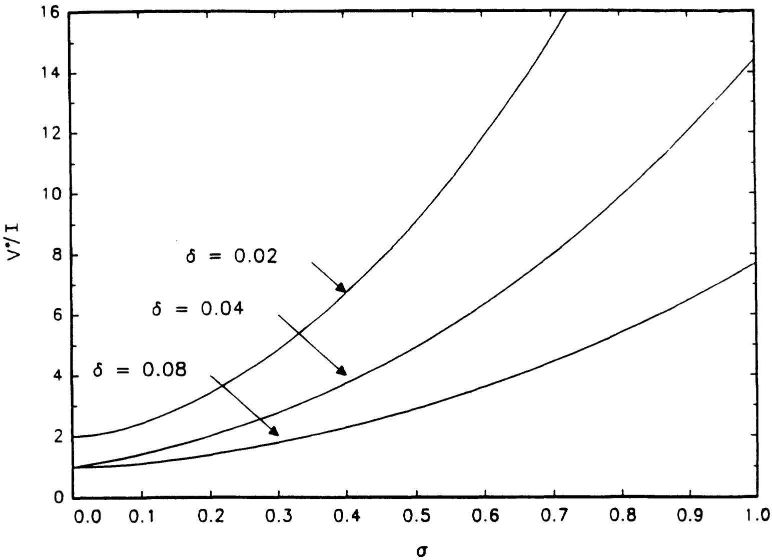
and

$$a = \frac{V^* - I}{(V^*)^{\beta}} = \frac{(\beta - 1)^{\beta - 1}}{\beta^{\beta} I^{\beta - 1}}. \tag{6}$$

The important point here is that because $\beta > 1$, $V^* > I$. Thus, uncertainty and irreversibility drive a wedge between the critical value V^*

7. The reader can check that $\beta > 1$, that $\lim_{\sigma \to \infty} \beta = 1$, and that $\lim_{\sigma \to 0} \beta = \rho/(\rho - \delta)$. (Hence, $\lim_{\sigma \to 0} \beta = \infty$ if $\delta = \rho$, i.e., if $\alpha = 0$.)

Figure 1 DEPENDENCE OF V^*/I ON σ.



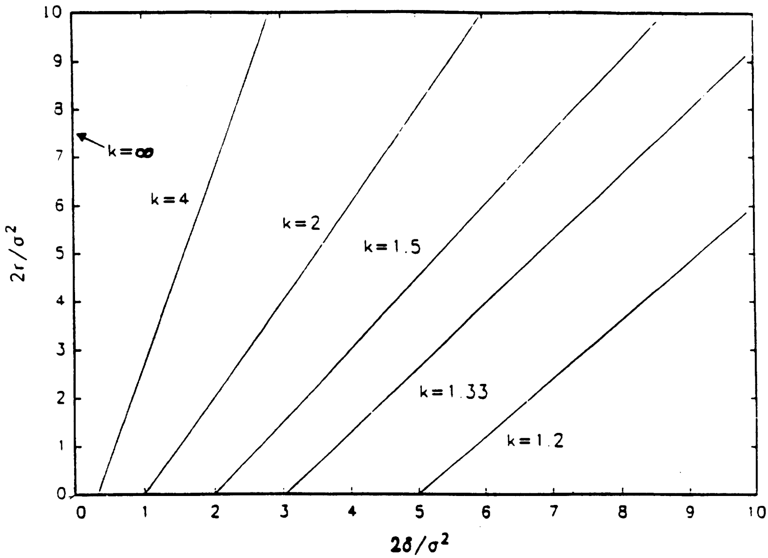
and the cost of the investment I.[8] Also, because $\partial\beta/\partial\sigma < 0$, this wedge is larger the greater is σ, i.e., the greater is the amount of uncertainty over future values of V.

2.1 CHARACTERISTICS OF THE INVESTMENT DECISION

It has been shown in several studies that the wedge between V^* and I can be quite large for reasonable parameter values, so that investment rules that ignore the interaction of uncertainty and irreversibility can be grossly in error. For example, if $\alpha = 0$ and $\rho = \delta = .05$, V^*/I is 1.86 if $\sigma = .2$, and is 3.27 if $\sigma = .4$. These numbers are conservative; in volatile markets, the standard deviation of annual changes in a project's value can easily exceed 20–40%. Figure 1 shows V^*/I as a function of σ for $\rho = .04$ and $\delta = .02$, .04, and .08. Note that moderate changes in σ (e.g., from 0.3 to 0.4) can lead to large changes in V^*/I, particularly if δ is small. Hence, investment decisions can be highly sensitive to the extent of volatility.

8. If $\alpha > 0$ so that $\delta < \rho$, $V^* > I$ even if $\sigma = 0$. The reason is that by delaying the investment, the present value of the cost is reduced at a rate ρ, whereas the present value of the payoff is reduced at the smaller rate $\rho - \alpha$. Hence, there is again a value of waiting. See Chapter 5 of Dixit and Pindyck (1993) for a detailed discussion of this point.

Figure 2 CURVES OF CONSTANT $k = \beta/(\beta - 1)$.



To see how the optimal investment rule depends on the other parameters, suppose the firm is risk-neutral and $\rho = r$, where r is the risk-free interest rate. Let $k = V^*/I = \beta/(\beta - 1)$ denote the multiple of I required to invest. Figure 2 shows iso-k lines plotted for different values of $2r/\sigma^2$ and $2\delta/\sigma^2$. We have scaled r and δ by $2/\sigma^2$ because k must satisfy:

$$\frac{2r}{\sigma^2} = k\left(\frac{2\delta}{\sigma^2}\right) - \frac{k}{k-1}.$$

As the figure shows, the multple k is smaller when δ is large and larger when r is large. As δ becomes larger (holding everything else constant except for α), the expected rate of growth of V falls, and, hence, the expected appreciation in the value of the option to invest and acquire V falls. In effect, it becomes costlier to wait rather than invest now.

On the other hand, when r is increased, $F(V)$ increases, and so does V^*. The reason is that the present value of an investment expenditure I made at a future time T is Ie^{-rT}, but the present value of the project that one receives in return for that expenditure is $Ve^{-\delta T}$. Hence, if δ is fixed, an increase in r reduces the present value of the cost of the investment but does not reduce its payoff. But note that while an increase in

r raises the value of a firm's investment options, it also results in fewer of those options being exercised. Thus, higher (real) interest rates can reduce investment, but for a different reason than in the standard model. In the standard model, an increase in the interest rate reduces investment by raising the cost of capital; in this model it increases the value of the option to invest and, hence, increases the opportunity cost of investing now.

In practice, however, an increase in r is likely to be accompanied by an increase in δ, because α is unlikely to increase commensurately with r. The reason is that the expected rate of capital gain on a project need not move with market interest rates. Hence, it may be more reasonable to assume that α remains fixed when interest rates change; then $\delta = r - \alpha$ will move one-for-one with r. As Figure 2 shows, if r and δ *both* increase by the same amount, the multiple k will fall. Thus, an increase in interest rates can *stimulate* investment in the short run by reducing the incentive to wait.

In summary, this simple model shows how uncertainty and irreversibility create an opportunity cost of investing, which increases the expected return required for an investment. That opportunity cost is an increasing function of the volatility of the project's value, so that an increase in volatility can, in the short run, reduce investment. An increase in the real interest rate has an ambiguous effect and could conceivably lead to a short-run increase in investment. Note, however, that these results tell us nothing about the long-run equilibrium relationship between uncertainty and investment.

2.2 RELATED MODELS OF IRREVERSIBLE INVESTMENT

In this basic model, the firm decides whether to invest in a single, discrete project. Much of the economics literature on investment focuses on incremental investment. In the standard theory, firms invest up to the point where the value of a marginal unit of capital just equals its cost (where the latter may include adjustment costs). When demand and/or operating costs evolve stochastically, this calculation is affected in two different ways.

First, uncertainty over future prices or costs can increase the value of the marginal unit of capital, which leads to more investment. This only requires that the stream of future profits generated by the marginal unit be a convex function of the stochastic variable; by Jensen's inequality, the expected present value of that stream is increased. This result was demonstrated by Hartman (1972) and later extended by Abel (1983) and others. In their models, constant returns to scale and the substitutability of capital with other factors ensure that the marginal profitability of capital is convex in output price and input costs. But even with fixed proportions, this convexity can result from the ability of the firm to vary output, so that the marginal unit of capital need not be utilized at times when the output price is low or input costs are high.[9]

As we have seen, when the investment is irreversible and can be postponed, the second effect of uncertainty is to create an opportunity cost of investing now, rather than waiting for new information. This increases the full cost of investing in a marginal unit of capital, which reduces investment. Hence, the net effect of uncertainty on irreversible investment depends on the size of this opportunity cost relative to the increase in the value of the marginal unit of capital. Pindyck (1988) and Bertola (1989) developed models in which a firm faces a downward-sloping demand curve, and showed that the net effect is negative—the opportunity cost increases faster than the value of the marginal unit of capital.

Hence, whether the investment decision is in terms of incremental capital or a discrete project, uncertainty over the future cash flows that the new capital generates creates a wedge between V^* and I. But as one would expect, a wedge of this kind can also result from uncertainty over policy or market-driven variables such as interest rates or tax rates. This has been illustrated in several recent theoretical studies.

For example, Ingersoll and Ross (1992) examined irreversible investment decisions when the interest rate evolves stochastically, but future cash flows are certain. They showed that as with uncertainty over future cash flows, this creates an opportunity cost of investing, so that the traditional NPV rule will accept too many projects. Instead, an investment should be made only when the interest rate is below a critical rate, r^*, which is lower than the internal rate of return, r^0, which makes the NPV zero. The difference between r^* and r^0 grows as the volatility of interest rates grows. Ingersoll and Ross also showed that for long-lived projects, a decrease in expected interest rates for all future periods need not accelerate investment. The reason is that such a change also lowers the cost of waiting and, thus, can have an ambiguous effect on investment. As another example, Rodrik (1989) examined the effects of uncertainty over policy reforms designed to stimulate investment (e.g., a tax incentive). He shows that if each year there is some probability that

9. Then the marginal profitability of capital at a future time t is $\max[0, (P_t - C_t)]$, where C_t is variable cost. Thus, a unit of capital is like a set of call options on future production, which are worth more the greater the variance of P_t and/or C_t.

the policy will be reversed, the resulting uncertainty can eliminate any stimulative effect that the policy would otherwise have on investment.[10]

Studies such as these suggest that levels of interest rates and tax rates may be of only secondary importance as determinants of aggregate investment spending in the short run; changes in interest rate volatility and policy instability may be more important. At issue is whether there is empirical support for this view. We will turn to that question after considering the effects of uncertainty in the context of a market equilibrium.

2.3 INDUSTRY EQUILIBRIUM

So far we have discussed investment decisions by a single firm, taking price (or, for a monopolist, demand) as exogenous. Our concern, however, is with investment at the industry or aggregate level, so that price is endogenous. When one is studying the effects of uncertainty on investment in the context of an industry equilibrium, two issues arise. First, we must distinguish among the sources of uncertainty—aggregate (i.e., industrywide) uncertainty and idiosyncratic (i.e., firm-level) uncertainty can have very different effects on investment. Second, the mechanism by which uncertainty affects investment is somewhat different at the industry or aggregate level than it is for an isolated firm.

The fundamental determinants of investment are the distributions of future values of the marginal profitability of capital—if these distributions are symmetric (and the firm is risk-neutral), uncertainty will not affect investment. For a monopolist, irreversibility causes the distributions to be asymmetric because the firm cannot disinvest in the future if negative shocks arrive; hence, the firm invests less today to reduce the frequency of bad outcomes in the future (i.e., the frequency of situations in which the firm has more capital than desired). In a competitive industry with constant returns to scale, the distribution of the future marginal profitability of capital for any particular firm is independent of that firm's current investment. But this distribution is not independent of *industrywide* investment.

This makes it important to distinguish between aggregate and idiosyncratic uncertainty. To see this, consider idiosyncratic and aggregate

10. Aizenman and Marion (1991) developed a similar model in which the tax rate can rise or fall, and showed that this uncertainty can, in the short run, reduce irreversible investment in physical and human capital, and thereby suppress growth. They also show that various measures of policy uncertainty are in fact negatively correlated with real GDP growth in a cross section of 46 developing countries.

shocks to productivity that are both symmetrically distributed. Although either type of shock can affect the expected future market price and, hence, the expected marginal profitability of capital, the idiosyncratic shocks will lead to an asymmetric probability distribution for the marginal profitability only insofar as the marginal revenue product of capital is convex in the stochastic variable. Aggregate shocks, however, will always lead to an asymmetric distribution. Although negative shocks can reduce the market price, positive shocks will be accompanied by the entry of new firms and/or expansion of existing firms, which will limit any increases in price. As a result, the distribution of outcomes for individual firms is truncated; negative shocks to productivity will reduce profits more than positive shocks will increase them, and irreversible investment will be reduced accordingly.[11]

In a recent paper, Caballero and Pindyck (1992) examined the effects of idiosyncratic and aggregate uncertainty using a simple model of a competitive market in which firms have constant returns to scale, and there is a sunk cost of entry. In their model, the marginal product of capital is linear in the stochastic state variables, thereby eliminating the positive Jensen's inequality effect of uncertainty on the value of a marginal unit of capital that arises from the endogenous response of variable factors to exogenous shocks. This lets them focus on the way in which the effects of uncertainty are mediated through the equilibrium behavior of all firms. They derive the critical rate of return required for investment and show how it is affected by aggregate (and not idiosyncratic) uncertainty, as well as other parameters. They also show that the basic implications of the model are supported by two-digit U.S. manufacturing data. In the next section, we show how a version of that model can be used to study uncertainty and investment across countries.

3. *Volatility, the Required Return, and Investment*

In this section we summarize the model in Caballero and Pindyck (1992), slightly modified to allow for differentiated products. We then review some implications of the model for the behavior of the required rate of return and investment at the industry and aggregate economywide levels.

Consider an economy with a large number $N(t)$ of very small firms

11. See Pindyck (1993) and Chapters 8 and 9 of Dixit and Pindyck (1993) for more detailed discussions of this point, and Dixit (1991), Leahy (1991), and Lippman and Rumelt (1985) for models of competitive equilibrium with irreversible investment.

producing what may be differentiated products, and let $Q(t)$ be an index of aggregate consumption that reflects tastes for diversity. We will represent $Q(t)$ by the CES function:

$$Q(t) = \left[\int_0^{N(t)} [A_i(t)]^\rho di\right]^{1/\rho}; \qquad 0 < \rho < 1, \tag{7}$$

where $A_i(t)$ is the output of firm i. Hence, the elasticity of substitution between any two goods is $1/(1 - \rho) > 1$.

Caballero and Pindyck decomposed the $A_i(t)$'s into average (aggregate) and idiosyncratic components, and allowed each component to follow a stochastic process. We also decompose $A_i(t)$, but we assume that the idiosyncratic component is constant:

$$A_i(t) = A(t)a_i, \text{ such that } \int_0^{N(t)} a_i di = N(t).$$

Thus, $A(t)$ is average productivity, so that $Q(t) = A(t)N(t)$, and a_i is the productivity of unit i relative to the average. Note that $N(t)$ can fluctuate over time, even though the a_i's are constant, as firms enter or exit. We will assume that aggregate productivity, $A(t)$, follows an exogenous stochastic process, and that the a_i's are randomly and uniformly distributed across firms. At issue is whether each firm knows its own a_i before entering, or only learns it after entering; we address this below.

We take aggregate demand to be isoelastic:

$$P(t) = M(t)Q(t)^{-1/\eta}, \tag{8}$$

where $M(t)$ also follows an exogenous stochastic process representing aggregate demand shocks. We also assume that there is an exogenous rate of depreciation or firm "failures," δ, so that in the absence of entry, $dN(t)/dt = -\delta N$.

Assume for now that firms only learn their relative productivities a_i after entry, so there is no selective entry. Hence, before entry, every firm expects to face the same price P. (Ex post, some firms will produce more than others, so actual prices will vary.) To introduce irreversibility, we assume that entry requires a sunk cost F. Then, free entry implies that:

$$F \geq E_0\left[\int_0^{\infty} P(t)A(t)e^{-(r+\delta)t}\, dt\right], \tag{9}$$

where r is the discount (interest) rate. The expectation E_0 is over the distribution of the future marginal profitability of capital, $P(t)A_i(t)$ and, therefore, accounts for the possible (irreversible) entry of new firms.

As long as we assume that firms cannot enter selectively, the results in Caballero and Pindyck again apply. In this case, the marginal profitability of capital for a firm considering entry is the average value of output, which we denote by $B(t)$:

$$B(t) \equiv P(t)A(t) = M(t)A(t)^{(\eta-1)/\eta}N(t)^{-1/\eta}. \tag{10}$$

We will assume that $A(t)$ and $M(t)$ follow uncorrelated geometric Brownian motions with drift and volatility parameters α_a and σ_a, and α_m and σ_m, respectively. Then $B(t)$ will follow a regulated geometric Brownian motion; entry will keep $B(t)$ at or below a fixed boundary U. When entry is not occurring, $B(t)$ will follow a geometric Brownian motion, with a rate of drift:

$$\beta = \alpha_m - \frac{1}{2}\sigma_m^2 + \frac{\delta}{\eta} + \frac{\eta-1}{\eta}\alpha_a - \frac{\eta-1}{2\eta}\sigma_a^2,$$

and with volatility:

$$\sigma_b = \sqrt{\sigma_m^2 + \left(\frac{\eta-1}{\eta}\right)^2\sigma_a^2}.$$

As shown in Caballero and Pindyck (1992), the boundary U is given by:

$$\frac{U}{F} = \frac{\lambda}{\lambda-1}\left(r + \delta - \beta - \frac{1}{2}\sigma_b^2\right), \tag{11}$$

where[12]

$$\lambda = \frac{-\beta + \sqrt{\beta^2 + 2(r+\delta)\sigma_b^2}}{\sigma_b^2}. \tag{12}$$

It is easy to show that $E_0\int_0^\infty Ue^{-(r+\delta)t}dt > F$. Because of irreversibility, there is an opportunity cost of investing now rather than waiting; if

12. A solution will exist if the discount rate is large enough so that the value of a firm remains bounded even if future entry is prohibited. This requires that $r + \delta - \beta - \sigma_b^2/2 > 0$, so that $\lambda > 1$.

firms could "uninvest" and recoup the cost F, we would instead have the Marshallian result that $E_0 \int_0^\infty Ue^{-(r+\delta)t}dt = F$. It can also be shown that $\partial(U/F)/\partial\sigma_b > 0$ and $\partial(U/F)/\partial\beta < 0$, i.e., the opportunity cost increases when the volatility of $B(t)$ increases, and decreases when the rate at which $B(t)$ is expected to approach U increases. The reason for this first result should already be clear. As for the second, an increase in β implies that $B(t)$ will on average be closer to U, so that there is a reduced risk of "bad" outcomes and, hence, a smaller opportunity cost of making a sunk cost investment.

Note that in this model, there is no investment until the expected "return" on a new unit of capital, $B(t)/F$, reaches the critical level U/F, and then investment occurs so that $B(t)/F$ cannot rise above this level. This is a result of our assumption that there is no selective entry, so that all firms face the same threshold for investment. It would be more reasonable to assume that firms, which are heterogeneous, have at least some knowledge of their relative productivities before they enter, so that they have different thresholds. Then different firms will invest at different times, and for every firm the required threshold will increase if the volatility of aggregate demand or productivity increases.

For example, suppose all potential entrants know their a_i's before entry. Then the free entry condition (9) becomes:

$$F \geq a_i E_0 \left[\int_0^\infty P(t)A(t)e^{-(r+\delta)t}dt \right]. \tag{13}$$

Now the value of output for firm i is $B_i(t) = a_i P(t)A(t) = a_i B(t)$, and the firm will invest when B_i reaches a threshold U_i. However, in this case the value of the firm will depend not only on $B(t)$, but also on the number of firms $N(t)$ currently producing. This adds another state variable to the problem, so that (given some distribution for the a_i's) finding U_i requires the solution of a partial differential equation for the value function.

3.1 EMPIRICAL IMPLICATIONS

It is important to be clear about what this model and others like it do and do not tell us about uncertainty and its effects on investment. First, note that these models do not describe investment per se, but rather the critical threshold required to trigger investment. In the model of an industry equilibrium discussed earlier, the threshold is U; in the simple model of investment in a single project reviewed in the preceding section, the threshold was a critical project value, V^*. In both cases the predictions of the models were with respect to the dependence of the threshold on volatility and other parameters. The models tell us that if volatility increases, the threshold increases.[13] Only to the extent that we can also describe (or make assumptions about) the distribution across firms of the values of potential projects, or of the marginal profitability of capital, can we also derive a structural model that relates volatility to actual investment.

Even without going this far, we can draw inferences from these models with regard to the ways in which investment should respond in the short run to changes in volatility and other parameters. For example, a one-time increase in volatility should reduce investment at least temporarily, because project values that were above or close to what was a lower critical threshold are now below a higher one. Second, we saw in our equilibrium model above that an increase in the drift, β, lowers the critical threshold and, hence, should be accompanied by an increase in investment.[14] Hence, increases in the volatility of the marginal profitability of capital, or decreases in its average growth rate (when it is below the boundary U), should lead to at least a temporary decrease in investment. In the next section, we will discuss this in more detail in the context of our empirical tests.

Unfortunately, there is very little that can be said about the effects of uncertainty on the long-run equilibrium values of investment, the investment-to-output ratio, or the capital-output ratio. To see this, note that although we know that an increase in volatility raises the *required return* needed to trigger investment, we do not know what it will do to the *average realized return*. The reason is that the firm requires a higher return to invest when volatility is higher, but it does so exactly because it is more likely to encounter periods of very low returns (when it will find itself holding more capital than it needs).

Or, consider the investment-to-output ratio, I/Q. In long-run equilibrium, we have $I/Q = \delta K P_K / Q(K)P = (P_K/P)(\delta K/Q(K))$. If the volatility of the marginal revenue product of capital increases, the required return increases, and investment falls for any given set of prices, so that the

13. This is not exactly correct, in that we have assumed in these models that volatility is constant. If volatility can change, predictably or unpredictably, then in principle the process by which it changes should be part of the model. However, models of financial option valuation in which volatility follows a stochastic process suggest that adding this complication would not change our results substantially. For examples of option valuation models with stochastic volatility, see Hull and White (1987), Scott (1987), and Wiggins (1987).

14. Remember that $B(t)$, the marginal profitability of capital, follows a regulated and therefore stationary process. The parameter β is the drift of $B(t)$ when it is below the threshold (i.e., upper boundary), U.

price of output P rises and P_K/P falls. Suppose the production technology is Cobb-Douglas with constant returns. Then $\delta K/Q(K) = \delta/AL^{\alpha}K^{-\alpha}$ rises. These two effects work in the opposite direction, so we are unable to conclude what will happen to I/Q. Another way to see this is to note that, as before, an increase in volatility results in a higher threshold but also a greater frequency in which the firm holds more capital than it needs, so that the productivity of capital could fall on average, i.e., I/Q could rise. Hence, we cannot claim on theoretical grounds, for example, that countries with more volatile or more unstable economies should have, on average, lower ratios of investment to GDP or lower capital-output ratios than countries with more stable economies.

For this reason, Caballero and Pindyck framed their tests in terms of the required return U/F. Although U/F cannot be observed directly, one can obtain a proxy for this variable by using extreme values of the marginal profitability of capital—e.g., the maximum over some period of time, or an average of the values in the highest decile or quintile. Caballero and Pindyck showed that for U.S. manufacturing data, such proxies indeed show a positive dependence on the volatility of the marginal profitability of capital. As discussed later, we will perform versions of such tests using aggregate country data. However, we will also examine how period-to-period movements in volatility affect investment.

4. *Methodology and Data*

We have seen that the threshold that triggers investment depends on the characteristics of the marginal profitability of capital—in particular, its volatility and its average rate of growth when it is below the threshold. Therefore, we begin by positing a simple production structure and calculating time series for the marginal profitability of capital for a set of countries. We then use these time series to obtain measures of volatility. This section describes these procedures, discusses the data, and explains our statistical methodology.

4.1 FRAMEWORK OF ANALYSIS

We assume that the economy is competitive, and we represent the gross value of output (GDP plus the value of imported material inputs) by a Cobb-Douglas production function with constant returns to scale:

$$Y = AK^{\alpha_K}L^{\alpha_L}M_I^{\alpha_M} \qquad \text{with } \alpha_K + \alpha_L + \alpha_M = 1, \tag{14}$$

where Y is the real gross value of output, i.e., real GDP plus the real value of imported materials (M_I), and K and L are inputs of capital and labor. Let P_L and P_M denote the *real* (i.e., relative to the price of output) prices of labor and imported materials. Then we can write the marginal profitability of capital as:

$$\Pi_K = \alpha_K \alpha_L^{\alpha L/\alpha K} \alpha_M^{\alpha M/\alpha K} A^{1/\alpha K} P_L^{-\alpha L/\alpha K} P_M^{-\alpha M/\alpha K}. \tag{15}$$

Now substitute $A = Y/K^{\alpha K} L^{\alpha L} M_I^{\alpha M}$ into this expression:

$$\Pi_K = \alpha_K \alpha_L^{\alpha L/\alpha K} \alpha_M^{\alpha M/\alpha K} \left(\frac{Y}{K^{\alpha K} L^{\alpha L} M_I^{\alpha M}} \right)^{1/\alpha K} P_L^{-\alpha L/\alpha K} P_M^{-\alpha M/\alpha K}. \tag{16}$$

Note that Π_K is the average value of output $B(t)$, as given by Equation (10). We will work with $b(t) = \log B(t)$:

$$b(t) = \log (\alpha_K \alpha_L^{\alpha L/\alpha K} \alpha_M^{\alpha M/\alpha K}) + \frac{a_t}{\alpha_K} - \frac{\alpha_L}{\alpha_K} p_{L,t} - \frac{\alpha_M}{\alpha_K} p_{M,t}, \tag{17}$$

where $a_t = y_t - \alpha_K k_t - \alpha_L l_t - \alpha_M m_t$ is the Solow residual, and where lowercase letters represent the logs of the corresponding uppercase variables.

We calculate $b(t)$ using Equation (17) for a set of 30 countries, of which 14 are LDCs, and the remainder are OECD countries. For each country, we use aggregate data on real (in local currency terms) GDP, the quantities of imported materials, labor, and capital, and the corresponding price indices. (We use the real exchange rate as the price index for imported materials.) We discuss the calculation of $b(t)$ in more detail below and in the Appendix.

Given these series for $b(t)$, we gauge the importance of uncertainty for investment in the following ways:

1. We first use extreme values of $b(t)$ as proxies for the threshold $u = \log U$ for each country. (We use four proxies—an average of the three largest values of $b(t)$ over the sample period, an average of the six largest values, and an average of those values of $b(t)$ that correspond to the three or six years with the highest rates of investment.) Next, we calculate the sample standard deviation of the annual changes in $b(t)$ over the full sample period, and the average rate of change of $b(t)$ over periods that exclude the extreme values. We then run cross-sectional regressions to determine whether the threshold proxies are indeed positively related to the sample standard deviation and negatively related to the average growth rate. These regressions also let us estimate the semi-elasticity that measures the percentage change in the required return corresponding to a change in the standard deviation.

2. We next measure the short- to intermediate-term dependence of investment on volatility by dividing the sample into three subperiods—1962–1971, 1972–1980, and 1981–1989—and calculating the sample mean and sample standard deviation of the annual changes in $b(t)$ for each subperiod. We then run panel regressions to determine the dependence of the ratio of private investment to GDP on this standard deviation and mean in each period.

3. An increase in the volatility of the marginal profitability of capital should, at least in the short- to intermediate-term, reduce real interest rates. Recall from our discussion in Section 2 that investment is likely to be highly inelastic with respect to the interest rate (and may even be an increasing function of the interest rate). Hence, an increase in the volatility of $b(t)$ (or decrease in its mean growth rate) that shifts the investment schedule to the left and leaves the saving schedule unchanged will result in a lower level of interest rates. To test this, we calculate the mean real interest rate for each of the three subperiods, 1962–1971, 1972–1980, and 1981–1989. We then run panel regressions to determine the dependence of the interest rate on the standard deviation and mean of the annual changes in $b(t)$ for each subperiod.

4. We would also like to know the extent to which the volatility of $b(t)$ can be explained by a variety of indicia of economic and political instability. Economic indicia that we examine include the mean rate of inflation, the standard deviation of annual changes in the inflation rate, and the standard deviations of annual changes in the real exchange rate and real interest rate. As political indicia, we consider the set of political instability variables used by Barro and Wolf (1991) in their study of growth, as well as the Cukierman-Edwards-Tabellini (1992) estimates of the annual probability of a change in government. As we will see, the mean inflation rate turns out to be the most robust explanator of volatility.

5. Finally, we focus on a group of six "low inflation" OECD countries and a group of six "high-inflation" developing countries in more detail, and examine the extent to which annual rates of investment for each group can be explained by annual rates of inflation as well as by other indicia of economic instability. We find that of these variables, inflation is the most significant explanator of investment, particularly during periods of high inflation.

4.2 THE DATA

To calculate the marginal profitability of capital, we work with the gross value of production, Y, which is the sum of real GDP plus the real value of imported materials, both measured in domestic currency units. The capital stock, K, is the real local currency value of each year's average stock of machinery, equipment, and nonresidential structures. Labor, L, is the total number of workers per year. Material inputs, M, is the real local currency value of imports of intermediate goods. The labor and capital shares α_L and α_K are at factor cost, net of capital consumption and indirect taxes, and the share of material inputs is $\alpha_M = 1 - \alpha_K - \alpha_L$. The real (product) wage is the average annual nominal wage divided by the GDP deflator, and the real price of imported inputs is a local currency price index of an import composite divided by the GDP deflator. The Appendix provides a more detailed description of the construction of the variables used in our analysis, and the sources of data.

Table 1 shows the standard deviation and mean of the annual log rate of change of $B(t)$, calculated for the three subperiods 1962–1971, 1972–1980, and 1981–1989, for our sample of 30 countries. Also shown is the average value of the ratio of private investment to GDP for each interval of time. Our regressions will use these subperiod averages, as well as averages for the entire sample period. Note that the standard deviations and means for the Philippines are about an order of magnitude larger than those for the other countries. This is due to very large annual fluctuations (up to 50%) in the data for the real wage in the Philippines. We find the wage data difficult to believe, so we omit the Philippines from our sample in all of the work that follows.

5. *Cross-Sectional Evidence*

In this section we use our cross section of countries to examine the dependence of investment and its determinants on the volatility of the marginal profitability of capital. We first work with proxies for the threshold (or required return) and then look directly at the dependence of investment on volatility using averages for our three subperiods. We also examine the dependence of interest rates on volatility, again using averages for the subperiods. In each case we will focus on differences between LDCs and OECD countries.

5.1 VOLATILITY AND THE REQUIRED RETURN

Changes in the volatility of the marginal profitability of capital affect investment by affecting the threshold at which firms invest. At the aggregate level, firms with different productivities will hit their thresholds at different times, so there will always be some investment taking place. When the marginal profitability of capital is high relative to its average value, more firms will be hitting their thresholds, and aggregate investment should be higher. Hence, although we cannot observe the threshold directly, we can use extreme values of $b(t)$ as a proxy.

Table 1 MARGINAL PROFITABILITY OF CAPITAL AND INVESTMENT

	1962–1971			*1972–1980*			*1981 On*		
Country	$SD\Delta B$	$\overline{\Delta B}$	*I/GDP*	$SD\Delta B$	$\overline{\Delta B}$	*I/GDP*	$SD\Delta B$	$\overline{\Delta B}$	*I/GDP*
Argentina	.066	.021	.101	.190	.108	.109	.221	−.069	.056
Brazil	.079	−.017	.153	.075	−.025	.209	.111	−.026	.133
Chile	.085	−.021	.092	.125	−.016	.071	.150	−.002	.096
Colombia	.030	.023	.179	.049	.030	.174	.043	−.033	.180
Hong Kong	.074	.014	.273	.099	−.007	.237	.102	.022	.227
Israel	.164	.022	.271	.145	−.037	.255	.086	.012	.185
Korea	.083	−.021	.102	.063	−.072	.199	.036	.002	.252
Malaysia	.036	.004	.181	.078	−.015	.280	.067	−.034	.324
Mexico	.032	.019	.136	.057	.006	.146	.048	−.020	.129
Taiwan	.072	.052	.090	.102	−.046	.126	.080	.002	.126
Philippines	.328	−.249	.140	1.182	−.225	.155	.987	−.311	.169
Singapore	.076	.106	.221	.082	−.002	.357	.071	.043	.401
Thailand	.000	−.135	.144	.049	.003	.180	.033	−.022	.178
Venezuela	.047	.005	.111	.062	−.060	.141	.113	−.057	.082
Austria	.055	.025	.205	.086	−.021	.218	.040	.018	.196
Belgium	.054	.010	.191	.115	−.082	.174	.140	.039	.146
Canada	.070	.015	.151	.092	−.012	.163	.118	.039	.186
Denmark	.150	−.001	.199	.158	−.046	.193	.100	.070	.156
Finland	.105	.003	.238	.089	.016	.237	.065	.057	.212
France	.048	−.014	.190	.123	−.063	.202	.084	.002	.172
Germany	.101	−.029	.212	.118	−.030	.185	.059	.009	.178
Ireland	.120	.083	.164	.356	−.077	.201	.144	.047	.178
Italy	.132	.021	.246	.136	.028	.211	.060	−.006	.176
Japan	.134	−.018	.231	.137	−.092	.258	.060	.028	.237
Netherlands	.077	.022	.210	.154	−.051	.183	.087	.016	.167
Norway	.048	.005	.231	.122	−.002	.252	.128	−.025	.224
Portugal	.102	−.015	.274	.289	−.166	.264	.134	.064	.242
Spain	.098	−.019	.206	.074	−.070	.226	.127	.036	.182
United Kingdom	.157	−.072	.138	.144	−.030	.142	.074	.014	.154
United States	.064	−.003	.159	.090	−.023	.163	.101	.029	.162

Note: For each subperiod, table shows the standard deviation ($SD\Delta B$) and mean ($\overline{\Delta B}$) of the annual log change in the marginal profitability of capital, $B(t)$, along with private investment as a percentage of GDP.

As in Caballero and Pindyck (1992), we examine several different variables. First, we compute the average of the top decile (three observations) of the 28 annual values of $b(t)$ for each country, which we denote by *DBDEC*, and the average of the top quintile (six observations), which we denote by *DBQUINT*. In both cases we calculate these values relative to the country mean of $b(t)$. We average over several extreme values rather than using the maximum value because $b(t)$ may rise above the threshold u temporarily if there are lags in investment or predictable temporary increases in $b(t)$.

An obvious problem with these proxies is that a higher standard deviation of the distribution of b's can imply larger extreme values of b even if the model were not valid. We therefore calculate alternative measures of u based on the behavior of investment itself. For each country, we calculate and order a series for the change in the real capital stock, $\Delta K(t)$, find the times t_1, t_2, and t_3 corresponding to its three largest values, and then find and average the corresponding values of $b(t)$; the resulting variable is denoted *DBKDEC*. Finally, we likewise calculate a variable *DBKQUINT* using those b's corresponding to the top six values of the ΔK's.

Table 2 shows cross-sectional regressions of each of these proxy variables on $SD\Delta B$, the sample standard deviation of $\Delta b(t)$, and $\overline{\Delta B}$, the sample mean of $\Delta b(t)$. (Note that $\overline{\Delta B}$ is calculated excluding the extreme values of $b(t)$ that are used in *DBDEC*, etc.) All of these regression results are consistent with the basic theory. In each regression the coefficients on $SD\Delta B$ are positive (although statistically significant only for *DBDEC* and *DBQUINT*), and the coefficients on $\overline{\Delta B}$ are negative.

As in Caballero and Pindyck, we can use these regression results to estimate the semi-elasticity $\Delta \log(U/F)/\Delta\sigma_b$, i.e., the percentage change in the required return corresponding to a change in the volatility. Using the *DBQUINT* and *DBKQUINT* regressions (which have the highest R^2 in each pair) puts this semi-elasticity in the range of 1–3. Thus, an increase of .05 in the standard deviation of annual percentage changes in the marginal profitability of capital should increase the required return on investment by 5–15%. To put this in perspective, such an in-

Table 2 CROSS-SECTIONAL REGRESSIONS OF THRESHOLD PROXIES

Dependent variable	*Const.*	$SD\Delta B$	$\overline{\Delta B}$	R^2
DBDEC	−.0203	3.536[a]	−2.150[a]	.638
	(.0604)	(0.627)	(1.465)	
DBQUINT	−.0249	3.225[a]	−3.601[a]	.652
	(.0579)	(0.573)	(1.377)	
DBKDEC	.0290	0.389	−4.518[a]	.153
	(.0842)	(0.814)	(2.035)	
DBKQUINT	−.0301	1.0419	−4.601[a]	.195
	(.0939)	(0.913)	(1.932)	

Note: $SD\Delta B$ is the sample standard deviation of $\Delta b(t) = \Delta \log B(t)$, and $\overline{\Delta B}$ is the sample mean of $\Delta b(t)$. Standard errors corrected for heteroscedasticity are shown in parentheses.
[a]Denotes significance at the 5% level.

crease in $SD\Delta B$ occurred in Venezuela and Spain between the periods 1972–1980 and 1981–1989 (see Table 1), so that if the required return in those countries had been 20%, it would rise to about 21–23%. This is a qualitatively important (but not overwhelming) effect and is similar to the results obtained by Caballero and Pindyck for two-digit U.S. manufacturing industries. (They found the semi-elasticity to be in the range of 1.2–1.8.)

These regression results also give us an estimate of the semi-elasticity $\Delta \log(U/F)/\Delta\beta$ in the range of -3 to -5. Thus, an increase in the drift of $\Delta b(t)$ of, say, .02 (which would not be atypical for the countries in our sample) would reduce the required return by 6–10%, e.g., from 20% to 18 or 19%. But note that this does not mean that an increase of productivity growth of 2% per year would reduce the required return for investment by 6 or 10%. Remember that β is the drift of $\Delta b(t)$ when $b(t)$ is below its threshold. Hence, this result only tells us that an economy in which productivity grew 2% faster than otherwise *during recoveries* would have a lower required return.

5.2 VOLATILITY AND INVESTMENT

We have estimated the extent to which an increase in volatility can increase the required return for investment, but without a model that describes the distribution of returns across firms and its evolution through time, we can say little about the effect of volatility on investment itself. Furthermore, the theory tells us nothing about the relationship between volatility and investment in a steady-state equilibrium; it only tells us that an increase in volatility (or decrease in the drift rate) should be accompanied by an at least temporary decrease in investment. To explore this, we divide our sample into three subperiods—1962–1971, 1972–80, and 1981–1989—and we calculate the sample mean and sample standard deviation of annual changes in $b(t)$ for each. We then run panel regressions that relate the ratio of private investment to GDP to these measures of the drift and volatility.

The regressions are shown in Table 3. Note that in each case, the number of observations is twice, and not three times, the number of countries (because the lagged investment-to-GDP ratio is an explanatory variable). Each equation includes a dummy variable for the 1981–1989 subperiod to account for structural change or other variables that might affect investment. Regressions are run for the full sample of 29 countries and then for the LDCs and OECD countries separately.

These regression results are mixed. They show a negative relationship between volatility and the rate of investment for the full sample, but the coefficients on $SD\Delta B_T$ are significant at the 5% level only for the

Table 3 REGRESSIONS OF PRIVATE INVESTMENT

Sample	*Const.*	*DU* M_{81-89}	$(IPRI/GDP)_{T-1}$	$SD\Delta B_T$	$\overline{\Delta B}_T$	R^2
All	5.042[a]	−3.223[a]	.9219[a]	−18.107	−4.160	.699
Countries	(1.942)	(1.061)	(.0957)	(9.900)	(8.363)	
All	5.086[a]	−3.358[a]	.9208[a]	−17.284		.698
Countries	(1.982)	(0.948)	(.0964)	(9.849)		
LDCs	7.330[a]	−4.151[a]	.9804[a]	−40.692[a]	3.341	.753
	(2.666)	(1.807)	(.1377)	(11.846)	(16.056)	
LDCs	7.187[a]	−4.180[a]	.9853[a]	−40.336[a]		.752
	(2.604)	(1.792)	(.1378)	(11.678)		
OECD	4.526[a]	−1.402	.7549[a]	2.005	−7.389	.755
	(1.342)	(0.791)	(.0750)	(5.787)	(8.753)	
OECD	4.464[a]	−1.848[a]	.7611[a]	3.889		.749
	(1.310)	(0.670)	(.0742)	(4.620)		

Note: Dependent variable is $(IPRI/GDP)_T$, the ratio of private investment to GDP, averaged over time interval T, where T = (1962–1971), (1972–1980), and (1981–1989), and measured in percentage points. $SD\Delta B_T$ is the sample standard deviation of $\Delta b(t) = \Delta \log B(t)$, and $\overline{\Delta B}_T$ is the sample mean of $\Delta b(t)$ for subperiod T. Standard errors corrected for heteroscedasticity are shown in parentheses.
[a]Denotes significance at the 5% level.

LDCs, and have the wrong sign for the OECD countries. This is the case whether or not we include the drift variable, $\overline{\Delta B}$, on the right-hand side. Also, note that the drift variable is positive (but insignificant) only for the LDCs.

For the LDCs, the implied effect of volatility on the rate of investment is moderately important. The estimate of the coefficient on $SD\Delta B_T$ is about −40, which means that an increase in volatility of .05 corresponds to a 2% drop in the investment-to-GDP ratio for a period of several years. This is a significant drop given that for most countries, the average ratios are less than 20%. The coefficient on $SD\Delta B_T$ is about half as large, however, for the full sample of 29 countries, and suggests that a .05 increase in the standard deviation of $\Delta b(t)$ would lead to less than a 1% drop in the ratio of investment to GDP.

5.3 VOLATILITY AND INTEREST RATES

As an additional experiment, we can examine one of the general equilibrium implications of the theory. To the extent that investment is highly inelastic with respect to the interest rate (or even an increasing function of the interest rate), and savings is an increasing function of the interest rate, an increase in the volatility of $b(t)$ should, at least in the short to intermediate term, reduce real interest rates. The reason is that an increase in the volatility of $b(t)$ (or decrease in its drift rate) should at least temporarily shift the investment schedule to the left, thereby lowering

Table 4 REAL INTEREST RATE REGRESSIONS

Sample	*Const.*	$SD\Delta B_T$	$\overline{\Delta B}_T$	$DU\ M_{81-89}$	R^2
All	.5930	−38.15	−61.15	11.015[a]	.294
Countries	(2.252)	(20.26)	(35.76)	(3.248)	
LDCs	2.471	−91.69[a]	−56.04	14.38[a]	.353
	(3.602)	(38.14)	(44.04)	(4.704)	
OECD	2.213	−10.67	4.132	4.677[a]	.597
	(1.249)	(5.772)	(14.33)	(1.397)	

Note: Dependent variable is R_T, the real interest rate averaged over time interval T, where T = (1972–1980) and (1981–1989). (The period 1962–1971 was omitted because of insufficient data.) Standard errors corrected for heteroscedasticity are shown in parentheses.
[a]Denotes significance at the 5% level.

interest rates. To test this, we calculate the mean real interest rate for each of the three subperiods and then run panel regressions to determine the dependence of the interest rate on $SD\Delta B$ and $\overline{\Delta B}$.

The regression results are shown in Table 4, first for the full sample of 29 countries, and then for LDCs and OECD countries separately. In each case the estimated coefficient of $SD\Delta B$ is negative as expected, and while it is statistically significant at the 5% level only for the LDCs, it is nearly significant for the full sample and for the OECD countries. Note that the coefficient estimate of −38 for the full sample implies that a .05 increase in the standard deviation of $\Delta b(t)$ leads to about a 200 basis point drop in the real interest rate. This is a very large effect, in part explained by the low interest-elasticity of savings found in cross-country savings regressions for developing countries.[15] This result must be viewed with caution, however, given the quality of the interest rate data for the LDCs. The estimated coefficient for $SD\Delta B_T$ is only about one fourth as large for the OECD countries. Also, note that the coefficient on $\overline{\Delta B}$ is always insignificant and has the wrong sign in two cases.

6. *Sources of Volatility*

We have seen in Section 3 that the volatility of the log of the marginal profitability of capital is a summary statistic that describes all of the uncertainty relevant for investment decisions. A question that then arises is to what extent can this volatility be explained by various indicia of economic and political instability. For example, does the level or volatility of inflation or the volatility of real exchange rates or interest

15. See Giovannini (1983) and Schmidt-Hebbel, Webb, and Corsetti (1992).

rates help to explain the volatility of $b(t)$? And do indicia of political instability, such as the political variables used by Barro and Wolf (1991) in their recent study of determinants of growth, have much to do with the volatility of $b(t)$? These questions are important because if increases in the volatility of $b(t)$ even temporarily depress investment, we would like to know what economic or political factors can cause such increases.

Table 5 shows simple correlations of $SD\Delta B$ with four economic indicia and seven political indicia of instability. The economic variables are the mean inflation rate (*INF*), the average annual standard deviation of the change in the inflation rate ($SD\Delta INF$), the average annual standard deviation of the change in the real exchange rate ($SD\Delta RER$), and the average annual standard deviation of the change in the real interest rate ($SD\Delta R$), in each case calculated over the full sample period for each country. The first political variable, *PROB*, is the annual probability of a change in government, as estimated from a probit model by Cukierman, Edwards, and Tabellini (1992), using data for the period 1948–1982. The other political variables, *ASSASS, CRISIS, STRIKE, RIOT, REVOL*, and *CONCHGE*, are the average number of assassinations, government crises, strikes, riots, revolutions, and constitutional changes per year over the period 1960–1985, and are from Barro and Wolf (1991). Table 5 shows correlations for the LDCs and for the OECD countries.

Table 5 CORRELATES OF VOLATILITY

Correlation of $SD\Delta B$ with	*LDCs*	*OECD*
INF	.4105	.3970
$SD\Delta INF$	.3816	.4414
$SD\Delta RER$	−.0851	.1014
$SD\Delta R$	.3096	.7213
PROB	−.0056	−.1922
ASSASS	.4026	−.0580
CRISIS	.0680	−.1887
STRIKE	.5891	−.1408
RIOT	.5054	−.0806
REVOL	−.0103	.0210
CONCHGE	−.2357	−.1022

Note: Table shows cross-sectional correlation coefficients for $SD\Delta B$ and various indicia of economic and/or political instability. *INF* is the mean inflation rate, $SD\Delta INF$ is the annual standard deviation of the change in the inflation rate, $SD\Delta RER$ is the standard deviation of the change in the real exchange rate, $SD\Delta R$ is the standard deviation of the change in the real interest rate, *PROB* is an estimate, by Cukierman, Edwards, and Tabellini (1992), of the probability of a change in government in any year, and *ASSASS, CRISIS, STRIKE, RIOT, REVOL*, and *CONCHGE* are the average number of assassinations, government crises, strikes, riots, revolutions, and constitutional changes per year, and are from Barro and Wolf (1991).

Only *INF*, *SDΔINF*, and *SDΔR* are significantly correlated with *SDΔB* for both the LDCs and OECD countries. However, these variables are also highly correlated with each other. (For example, the correlation of *INF* with *SDΔINF* is above .90.) Of the political variables, only *ASSASS*, *STRIKE*, and *RIOT* are significantly correlated with *SDΔB*, and then only for the LDCs.

We ran a large set of cross-sectional regressions in order to explore the ability of these economic and political variables to "explain" the volatility of $b(t)$. Table 6 shows only a small subset of these regressions, but the results are representative of our overall findings. Most important, the mean inflation rate is the only variable that is consistently significant as an explanator of *SDΔB*. Although *SDΔINF* and *SDΔR* are individually correlated with *SDΔB*, they are always insignificant when combined with *INF* in a regression. *STRIKE* is also significant in these regressions, but only for the LDCs. As long as *INF* is also in the regression, all of the other political variables are either insignificant and/or have the wrong sign. This is true for the LDCs, the OECD countries, or when the regressions are run over the full sample.

Table 6 EXPLAINING VOLATILITY

Const.	*INF*	*SDRER*	*PROB*	*CRISIS*	*RIOT*	*STRIKE*	R^2	*NOB*
A. LDCs								
.0625[a]	.00020	.0017					.478	13
(.0145)	(.00012)	(.0019)						
.0894[a]	.00014[a]	−.0010	−.0509				.172	8
(.0349)	(.00006)	(.0025)	(.0578)					
.0631[a]	.00004	−.0011		.0076	.0074	.0743[a]	.721	10
(.0164)	(.00008)	(.0014)		(.0565)	(.0085)	(.0268)		
B. OECD								
.0454[a]	.0113[a]	−.0005					.395	16
(.0303)	(.0031)	(.0027)						
.0903[a]	.0120[a]	−.0028	−.0700[a]				.440	16
(.0396)	(.0027)	(.0036)	(.0299)					
.0052	.0139	.0052		−.0042	.0001	−.0591	.361	14
(.0478)	(.0077)	(.0031)		(.0220)	(.0143)	(.0337)		

Note: Table shows regressions of *SDΔB* on indicia of economic and/or political instability. *INF* is the mean inflation rate, *SDΔRER* is the standard deviation of the annual change in the real exchange rate, *PROB* is an estimate, by Cukierman, Edwards, and Tabellini (1992), of the probability of a change in government, and *CRISIS*, *STRIKE*, and *RIOT* are the average number of government crises, strikes, and riots per year, and are from Barro and Wolf (1991). Standard errors corrected for heteroscedasticity are shown in parentheses.

[a]Denotes significance at the 5% level.

This suggests that strikes, riots, revolutions, and other forms of political turmoil and uncertainty (as measured by these indicia) may have little to do with uncertainty over the return on capital and, hence, with investment. It may mean that as long as a government can control inflation—an indicator of overall economic stability, and from which exchange rate and interest rate stability tend to follow—it can limit the uncertainty that matters for investment. These results also raise doubts regarding recent results in the literature that relate indicia of political instability to growth. On the other hand, regressions of the sort shown in Table 6 have serious limitations. Aside from the very limited sample of countries, the most important limitation is our assumption that the relevant stochastic state variables follow Brownian motions, so that $b(t)$ follows a controlled Brownian motion. This eliminates "peso problems" as a source of uncertainty.

If we take these results at face value, they suggest that controlling inflation should be one of the most important intermediate objectives of policy. We explore this in more detail in the next section.

7. *Time Series Evidence*

The cross-country evidence presented earlier suggests that inflation may be one of the best indicia of economic instability and is associated with lower rates of capital formation. This seems to be particularly true at very high levels of inflation. In this section we explore the relationship between inflation and investment in more detail by examining a group of six OECD countries that have had relatively low inflation and a group of high inflation countries, predominantly in Latin America. Our objective is to examine the robustness of the relationship between inflation and investment across countries with very different levels of inflation, and to explore possible nonlinearities in this relationship within each country group.

To do this, we study the relationship between year-to-year variation in different indicators of economic instability and the ratio of investment to GDP. This is important, because our use of nine-year averages in Section 5 may have concealed higher-frequency information. In this section we report on panel regressions that utilize annual data relating the ratio of investment to GDP (total and private) *directly* to three indicia of economic instability—the level and variability of inflation, and the variability of the real exchange rate. (Unfortunately annual data are not available for indicia of social and political instability.) This allows us to capture possible effects of economic instability on investment that may occur through channels other than the volatility of the marginal profitability of capital.[16]

Of particular concern to us is inflation, which can affect investment in several ways: (1) High and volatile inflation may indicate an inability of the government to control the economy (see Fischer, 1993). As a consequence, government policies will be perceived by investors as unsustainable and, hence, risky, leading them to defer investing. (2) High and volatile inflation is associated with greater volatility in the marginal profitability of capital, and with volatile relative prices (see Fischer and Modigliani, 1978, and Fischer, 1986). (3) Inflation amounts to a tax on real monetary balances. Hence, if money and capital are complementary—through the production function or through cash-in-advance constraints—inflation and investment will be negatively correlated.[17]

7.1 LOW-INFLATION OECD COUNTRIES

We first estimate a fixed effects panel regression for the ratio of total investment to GDP for France, Germany, Japan, The Netherlands, the United Kingdom, and the United States, using annual data covering the period 1960–1990. In this model, the investment-to-GDP ratio is a function of variables such as the rate of inflation, the standard deviation of the inflation rate, and the standard deviation of the real exchange rate, as well as the lagged rate of real GDP growth and the lagged investment-to-GDP ratio. In the estimation, the White procedure was used to correct for heteroscedastic errors, and the H-test did not reject the null hypothesis of absence of first-order serial correlation. Each variable is measured as a deviation from its corresponding country mean, so that the model can be written as:

$$(I/GDP)_{i,t} = a_1 INF_{i,t} + a_2 SDINF_{i,t} + a_3 SDRER_{i,t} + a_4 GRTH_{i,t-1} + a_5 (I/GDP)_{i,t-1} + \epsilon_{i,t} \qquad (18)$$

where $(I/GDP)_{i,t}$ is the ratio of investment to GDP in country i in year t, *INF* is the mean inflation rate for the year, *SDINF* is the sample standard deviation of each year's monthly observations of inflation, *SDRER* is

16. Fischer (1986, 1991, 1993) discusses several channels through which inflation may affect growth and capital formation.

17. Fischer (1993) and Kormendi and Meguire (1985) have found such a negative correlation.

the sample standard deviation of the real exchange rate, and *GRTH* is the ratio of growth of real GDP.

Selected results of estimating this model for total investment are shown in Table 7. (The results are similar for private investment.) The economic volatility variables *INF, SDINF,* and *SDRER* are highly correlated with each other, but when all three are included in the regression, only the coefficient of *INF* is negative and significant. *INF* is also highly significant in any pairwise combination with *SDINF* and *SDRER,* but *SDRER* is significant only by itself or in combination with *SDINF*. These results suggest that of the three indicia of economic volatility, the level of inflation is the most robust explanator of investment, but the volatility of relative prices—proxied by the volatility of the real exchange rate—has an independent contribution in explaining investment.

To further explore the relationship between inflation and investment

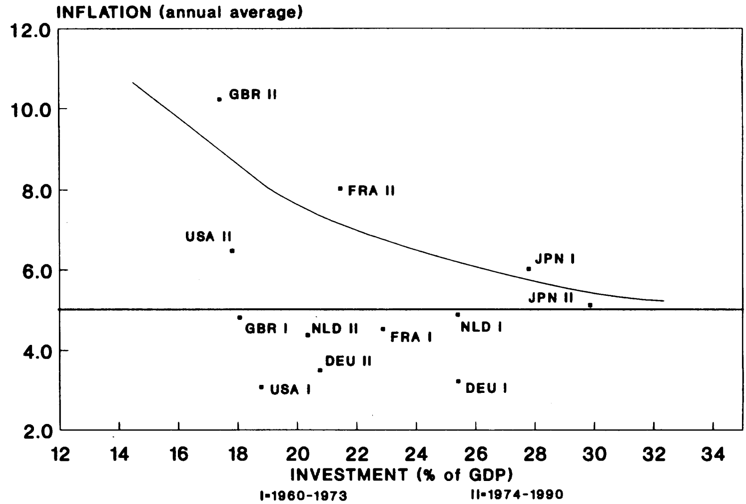
Table 7 PANEL REGRESSIONS—COUNTRIES: FRANCE, GERMANY, JAPAN, NETHERLANDS, UNITED KINGDOM, UNITED STATES

Eqn.	*Lagged Dep.*	$GRTH_{-1}$	*INF*	*SDINF*	*SDRER*	$\frac{IPUB}{GDP}$	R^2
A. Dependent Variable: *ITOT/GDP*							
(1)	.889[a]	.101[a]	−.088[a]	.0004	−.038		.867
	(.029)	(.024)	(.021)	(.489)	(.022)		
(2)	.851[a]	.117[a]		−.057	−.065[a]		.851
	(.030)	(.023)		(.509)	(.024)		
(3)	.889[a]	.101[a]	−.088[a]		−.038[a]		.867
	(.029)	(.023)	(.020)		(.022)		
B. Dependent Variable: *IPRI/GDP*							
(4)	.833[a]	.101[a]	−.053[a]		−.025		.782
	(.037)	(.023)	(.018)		(.020)		
(5)	.082[a]	.112[a]		−.220	−.038		.773
	(.036)	(.023)		(.444)	(.021)		
(6)	.833[a]	.099[a]	−.056[a]	.145	−.024		.783
	(.037)	(.024)	(.019)	(.463)	(.020)		
(7)	.890[a]	.090[a]	−.062[a]		−.052[a]	−.270[a]	.798
	(.038)	(.022)	(.020)		(.023)	(.100)	
(8)	.848[a]	.103[a]		−.275	−.065[a]	−.241[a]	.785
	(.038)	(.023)		(.460)	(.025)	(.100)	
(9)	.889[a]	.088[a]	−.065[a]	.136	−.051[a]	−.269	.798
	(.029)	(.024)	(.021)	(.482)	(.023)	(.099)	

Note: Each equation is a panel regression with 180 observations. *GRTH* is the rate of growth of real GDP, *INF* is the mean inflation rate for the year, *SDINF* is the sample standard deviation of each year's monthly observations of inflation, *SDRER* is the standard deviation of the real exchange rate, and *IPUB/GDP* is the ratio of public investment to GDP. Standard errors corrected for heteroscedasticity are in parentheses.

[a]Denotes significance at the 5% level.

Figure 3 TOTAL INVESTMENT AND INFLATION: FRANCE, GERMANY, JAPAN, THE NETHERLANDS, UNITED KINGDOM, AND UNITED STATES



for this group of countries, we show in Figure 3 the average values for both variables for the subperiods 1960–1973 and 1974–1990. Note that the negative relationship between inflation and the investment-to-GDP ratio is strongest for average rates of inflation above 5% per year; below that level the relationship is blurred. As the scatter diagram shows, most instances of average annual inflation rates over the 5% threshold belong to the period 1974–1990, when inflation accelerated and capital formation declined in the OECD largely as a consequence of the two oil price shocks and the subsequent adjustment process.

7.2 HIGH-INFLATION COUNTRIES (LATIN AMERICA AND ISRAEL)

Similar panel regressions were estimated for Argentina, Bolivia, Brazil, Chile, Israel, and Mexico, also using annual data for the period 1960–1990. Table 8 shows selected regressions results, first for total investment and then for private investment.

Note that inflation always appears with a negative coefficient, but is statistically significant only for the total investment regressions. The standard deviation of inflation is always insignificant (and has a coefficient of correlation with the level of inflation of .89 in this sample), and the standard deviation of the real exchange rate is negative and significant in two of the three total investment equations. These results are

Table 8 PANEL REGRESSIONS—COUNTRIES: ARGENTINA, BRAZIL, CHILE, MEXICO, ISRAEL, BOLIVIA

Eqn.	*Lagged Dep.*	$GRTH_{-1}$	*INF*	*SDINF*	*SDRER*	$\frac{IPUB}{GDP}$	R^2
A. Dependent Variable: *ITOT/GDP*							
(1)	.7616[a]	.1743[a]	−.00016[a]		−.0924[a]		.797
	(.0592)	(.0338)	(.00007)		(.0241)		
(2)	.7582[a]	.1774[a]		−.0304	.0748[a]		.797
	(.0621)	(.0340)		(.0316)	(.0349)		
(3)	.7571[a]	.1756[a]	−.00013[a]	−.0225	−.0766[a]		.797
	(.0621)	(.0339)	(.00006)	(.0318)	(.0348)		
B. Dependent Variable: *IPRI/GDP*							
(4)	.7529[a]	.1154[a]	−.00009		−.0365		.697
	(.0495)	(.0295)	(.00007)		(.0191)		
(5)	.7508[a]	.1172[a]		−.0107	−.0315		.697
	(.0503)	(.0293)		(.0269)	(.0320)		
(6)	.7511[a]	.1157[a]	−.00009	−.0054	−.0327		.697
	(.0503)	(.0294)	(.00006)	(.0271)	(.0321)		
(7)	.7676[a]	.1317[a]	−.00013		−.0420[a]	−.1229[a]	.708
	(.0505)	(.0321)	(.00007)		(.0199)	(.0538)	
(8)	.7634[a]	.1341[a]		−.0182	−.0324	−.1216[a]	.707
	(.0510)	(.0320)		(.0269)	(.0317)	(.0543)	
(9)	.7641[a]	.1324[a]	−.00011	−.0114	−.0341	−.1242[a]	.708
	(.0509)	(.0320)	(.00006)	(.0275)	(.0319)	(.0543)	

Note: Each equation is a panel regression with 180 observations. *GRTH* is the rate of growth of real GDP, *INF* is the mean inflation rate for the year, *SDINF* is the sample standard deviation of each year's monthly observations of inflation, *SDRER* is the standard deviation of the real exchange rate, and *IPUB/GDP* is the ratio of public investment to GDP. Standard errors corrected for heteroscedasticity are in parentheses.

[a]Denotes significance at the 5% level.

again consistent with the view that inflation, and to a lesser extent the variability of relative prices, are what matter most for investment. Finally, when the ratio of public investment of GDP is included in the equations for private investment, it is always negative and significant, suggesting a crowding out effect.

To explore potential nonlinearities in the relation between inflation and investment, and also to relate the duration of the spells of high inflation to their impact, it is useful to classify different inflationary experiences in terms of their intensity. One classification (more appropriate for "chronic" high-inflation countries) was proposed by Dornbusch and Fischer (1993): (1) *moderate inflation* refers to rates of price increase between 15 and 30% per year for at least three consecutive years; (2) *high inflation* refers to rates between 30 and 100% per year; (3)

extreme inflation refers to rates between 100 and 1,000% per year; and (4) *hyperinflation* refers to rates above 1,000% per year.[18]

Table 9 summarizes the experiences of inflation and their aftermath for several countries. It shows that the slide from "low" to "moderate" inflation has no significant effect on capital formation. On the contrary, in some cases, like Mexico and Korea in the mid to late 1970s, the slide from low inflation to moderate inflation came along with an increase in (mostly public) investment rates.[19]

On the other hand, Table 9 shows that in countries in which inflation went from low to high two-digit levels and then to three digits, investment was more severely affected. For example, in Mexico, Brazil, and Israel, investment declined by 5 percentage points of GDP (or more) in the 1980s (a period of severe acceleration of inflation in these countries) compared to the average levels of the 1960s and 1970s.

A more extreme case of protracted instability is Argentina. This country had an average annual inflation rate around 260% for 14 years—between 1975 and 1988—before drifting to hyperinflation in 1989–1990. This is a case of extremely prolonged inflation and at a very high level. No wonder, then, that capital formation collapsed in Argentina in the 1980s; the share of investment in GDP declined by more than 10 percentage points in the 1980s from its average of the 1960s and 1970s. Another extreme case is Bolivia, which experienced hyperinflation in 1984–1985.[20]

Regarding the duration of the spells of inflation, the data show that the higher the rate of inflation, the shorter the duration of the inflationary episode. Low and moderate inflation (below 30% per year) tend to be relatively stable, high inflation (between 30 and 100%) less so, three-digit inflations often last between 2 to 5 years, and hyperinflation may last from 6 months to 18 months.

Figures 4 and 5 show the relationship between inflation and the ratio of investment (total and private) to GDP for Argentina, Bolivia, Brazil, Chile, Israel, and Mexico, using decade averages for the 1960s, 1970s, and 1980s. These figures show a negative relationship between the average rate of inflation and the average investment-to-GDP ratio when

18. The norm of inflation clearly depends on the region or country. For several OECD economies, rates of inflation in excess of 10% per year would be considered as intolerable or "extreme."

19. See Lustig (1992) and Collins and Park (1989). In fact, in the short term, inflation and investment may move in the same direction following an increase in public investment or other exogenous demand shock.

20. The share of total investment in GDP in Bolivia was only 9% in the period 1983–1990, down from 23% in the preinflation period. The period 1983–1990 includes both the hyperinflation and its subsequent stabilization.

Table 9 DYNAMICS OF INFLATION AND INVESTMENT: SELECTED EPISODES

		Inflation rate (average % per year)			*Investment rate (% of GDP)*		
	Period	*3 Years before*	*In period*	*3 Years after*	*3 Years before*	*In period*	*3 Years after*
Episodes of moderate inflation (15–30% per year for at least 3 years)							
Mexico	1974–1976	7.4	18.3	21.6	22.1	23.8	22.9
United Kingdom	1974–1977	8.6	18.1	13.2	18.8	17.9	16.9
Episodes of high inflation (30–100% per year for at least 3 years)							
Mexico	1982–1986	24.1	74.0	88.6	26.5	19.2	17.9
Brazil	1976–1980	23.1	52.0	115.2	30.7	28.0	21.8
Israel	1974–1979	15.0	45.7	122.7	30.7	24.6	19.5

Episodes of extreme inflation (100–1000% per year for at least 2 years)							
Mexico	1987–1988	69.8	123.0	22.2	18.2	17.6	19.9
Argentina	1975–1988	47.3	265.3	1,835.5	16.7	14.3	7.7
Brazil	1983–1988	95.4	270.5	1,563.5	24.9	19.6	18.6
Israel	1980–1985	54.5	198.7	28.1	21.7	19.4	17.5
Chile	1973–1976	42.4	363.2	55.1	17.2	14.5	13.9
Episodes of hyperinflation (more than 1000% per year for at least 1 year)							
Argentina	1989–1990	188.1	2,696.9	91.3[a]	10.1	6.7	9.9[a]
Brazil	1989–1990	352.4	2,112.4	465.8[a]	20.9	19.1	17.6[a]
Bolivia	1984–1985	216.7	5,173.8	32.7	16.0	8.4	8.3

Source: Elaborated from data of World Bank and Hofman (1992), World Bank (1992).
[a] = 1991.

Figure 4 TOTAL INVESTMENT AND INFLATION: ARGENTINA, BOLIVIA, BRAZIL, CHILE, ISRAEL, AND MEXICO

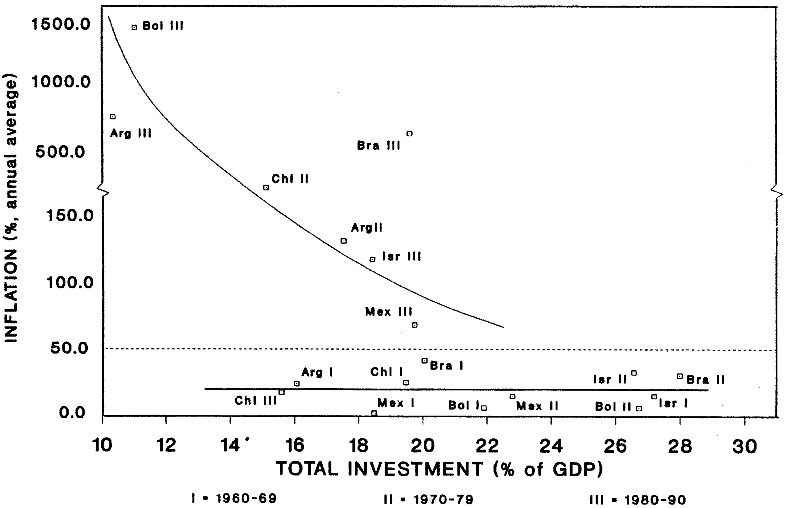
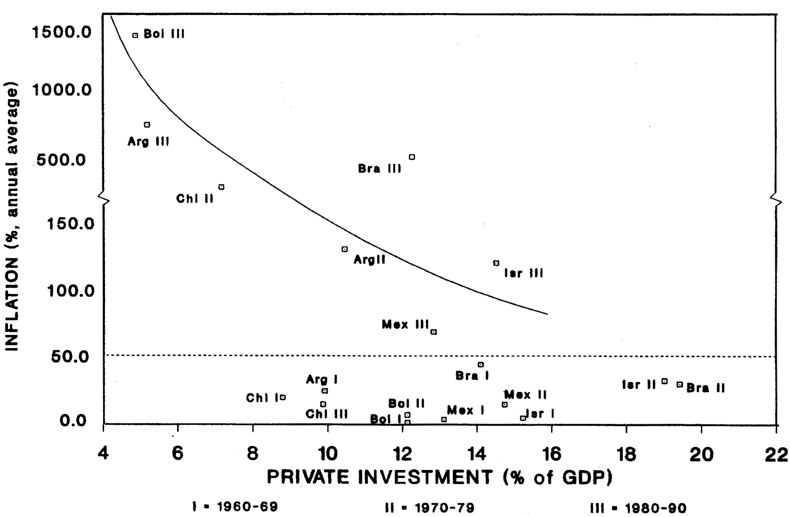


Figure 5 PRIVATE INVESTMENT AND INFLATION: ARGENTINA, BOLIVIA, BRAZIL, CHILE, ISRAEL, AND MEXICO



annual inflation is over 50% (particularly during the 1970s and 1980s). However, when the average annual inflation rate is less than 50% (e.g., in the 1960s), the relationship between inflation and investment is much less clear. This suggests that the relationship between inflation and investment is highly nonlinear.

7.3 STABILIZATIONS AND THE RESPONSE OF INVESTMENT

Stabilizing inflation is a precondition for a resumption of investment in an economy that has undergone a period of high price instability. However, accumulated evidence shows that the resumption of investment and growth after the implementation of a stabilization program is a slow process. There are several reasons for this: (1) Restrictive monetary policies push up real interest rates, thus depressing investment and output growth, and (2) there is a potential credibility problem in the aftermath of stabilization that makes investors reluctant to commit resources given doubts as to whether the stabilization program will succeed. This tends to delay the recovery of investment in the aftermath of stabilization. (3) Governments tend to cut public investment during the course of fiscal adjustment, and if public investment, particularly in infrastructure, telecommunications, and the like, is complementary with private investment, this will contribute to a decline in aggregate capital accumulation. (4) If the stabilization program takes place in a context of reduced foreign financing (e.g., Latin America in the 1980s), the resumption of investment in the aftermath of stabilization will be more elusive (see Sachs, 1989, and Serven and Solimano, 1992, 1993).

Table 10 summarizes four stabilization programs carried out in the 1970s and 1980s: Chile (1975), Israel (1985), Bolivia (1985), and Mexico (late 1987).[21] In three of the four cases, the investment share remained below its preinflation level during the first five years after the stabilization program was launched, suggesting that the resumption of investment (and growth) after the implementation of a stabilization program is a slow process.[22]

Also, there seems to be no correlation between the speed of disinflation and the speed of investment recovery. Bolivia ended its hyperinfla-

21. For recent studies of these stabilization programs, see Corbo and Solimano (1991) for Chile, Bruno and Meridor (1991) for Israel, Morales (1991) for Bolivia, and Ortiz (1991) for Mexico. Chile and Bolivia are cases of orthodox stabilization (money based), and Israel and Mexico are cases of heterodox stabilization (multiple-anchor); see Bruno et al. (1991) and Kiguel and Liviatan (1992).

22. For additional evidence on this for a larger group of countries, see Dornbusch (1991), Corden (1991), and Solimano (1992b).

Table 10 STABILIZATION AND ITS AFTERMATH: THE INVESTMENT RESPONSE. MEXICO, ISRAEL, BOLIVIA, CHILE

		Period of most intense inflation before stabilization			*Inflation rate (average % per year)*				*Investment (% of GDP, average)*			
Country	*Historical period (of low to moderate inflation)*	*High inflation*	*Extreme inflation*	*Hyper-inflation*	*Hist. period*	*Infl. period*	*3 Yrs. after*	*5 Yrs. after*	*Hist. period*	*Infl. period*	*3 Yrs. after*	*5 Yrs. after*
Chile	1961–1970		1973–1975		27.2	413.6	40.1	35.1	19.1	14.9	13.6	16.6
Israel	1961–1973		1980–1985		7.8	198.7	16.3	17.2	27.4	20.7	16.5	18.1
Bolivia	1961–1972			1984–1985	5.5	5,173.8	21.5	18.0	14.4	5.3	5.9	5.3
Mexico	1961–1981		1987–1988		10.6	123.0	19.9	—	20.7	16.4	18.9	—

Source: IMF (1992), World Bank (1992).

tion of 1985 very quickly, while investment remained depressed for many years thereafter. In contrast, disinflation in Chile after 1975 was slow, and the immediate investment response to the stabilization plan was fast.[23] As for the effect of program characteristics on the performance of investment after stabilization, the evidence shows no clear differences in the behavior of investment between orthodox (money-based) and heterodox (multiple-anchor-based) stabilization programs.

In summary, the country evidence shows that the restoration of stability after a period of high inflation and uncertainty is likely to be accompanied by depressed capital formation, because investors require time to be convinced that the uncertainty is indeed reduced and that stability will be consolidated.

8. *Conclusions*

We have outlined some of the empirical implications of the recent theoretical literature on irreversible investment and the value of waiting, and then examined its relevance for aggregate investment in a set of industrialized and developing countries. We have shown that if the exogenous stochastic state variables follow Brownian motions, uncertainty can be summarized by the volatility of the marginal profitability of capital, which will itself follow a controlled Brownian motion. An increase in this volatility will increase the critical required return for investment and, hence, should reduce investment spending—in the short run. Unfortunately, we can say little about the effect of such an increase in volatility on the long-run steady-state level of investment, investment-to-output ratio, or other such measures.

This does not mean, however, that volatility is not an important determinant of investment spending. Given the lags involved in planning and implementing large-scale investment programs, and given that the real and perceived riskiness of investing can change over decades, the "short run" can easily be 10 or 20 years.

We therefore conducted our empirical tests by examining the relationship between volatility and investment across decades for a set of countries. We found that the relationship is negative but moderate in size, and is of greater magnitude for developing countries. We also tried to relate the volatility of the marginal profitability of capital to indicia of economic instability—such as inflation and its volatility—and to indicia of political instability. Only inflation is at all robust as an explanator of the marginal profitability of capital. In addition, inflation is the only

23. See Solimano (1992a).

economic risk index that strongly explains investment in panel regressions using annual data. These results lend support to the view that controlling inflation should be one of the most important objectives of economic policy.

Our results are subject, however, to some important caveats. First, our construction of series for the marginal profitability of capital was problematic for several developing countries with poor or fragmentary data on the capital stock and on factor prices. The high aggregation level and poor data call for caution in interpreting the series for this variable for some countries. Future work in improving this data and extending it to the sectoral level is needed. Second, the size of our sample (29 countries) has been a limiting factor in this work, and needs to be enlarged if we are to obtain more conclusive results. Third, we have worked within the framework of a very simple theoretical model (i.e., a Cobb-Douglas production function with constant returns), so that we could ignore idiosyncratic sources of uncertainty, and easily estimate the marginal profitability of capital. Fourth, we have ignored the relationship between private and public investment (as well as associated measurement problems), nor have we examined possible differences in the effects of instability on different types of investment (e.g., equipment versus structures).

There are also fundamental problems in interpreting and measuring instability. The underlying probability of a future change in policy regime (a "peso problem") is not necessarily conveyed in our data and is an obvious limitation of our analysis. Understanding the forces that make one country or region persistently more unstable than others is a complex problem related to differences in basic economic structures, in the workings of fiscal and monetary institutions, and in the characteristics of the political process and the distributive conflicts it brings about.

Appendix

The inputs used to construct series for the marginal profitability of capital for each country, as well as the other variables used in this work, came from the following sources:

1. Gross Capital Stock: Local currency value at constant prices of year-average of the sum of machinery and equipment and nonresidential structures. It excludes government durable goods for military use. For those countries where a complete capital stock series was unavailable, the capital stock was constructed as follows: Given an initial value of the capital stock for a base year using actual data on gross investment and depreciation rates, we generated annual estimates of

the capital stock. The depreciation rate is chosen so that the generated value matches the actual value of the capital stock for another year in which there is available information. Sources: Argentina, Brazil, Chile, Colombia, Mexico, and Venezuela—Hofman (1991); Korea and Taiwan—Hofman (1992); Japan, The Netherlands, France, Germany, the United States, and the United Kingdom—Madison (1992); other countries—Dadkhah and Zahedi (1990) and estimation using the perpetual inventory method.

2. GDP, Investment GDP, and Investment Deflators: Real GDP in local currency. The ratio of investment to GDP is the ratio of real investment to real GDP (ratio of nominal investment to nominal GDP times the ratio of the GDP deflator to investment deflator). Sources: All countries—IMF database (1992); for Taiwan: World Bank database (1992).
3. Employment: Total workers per year. Source: Summers and Heston (1991).
4. Imported Materials: Defined as total imports minus imports of machinery and equipment, at real domestic currency values. Sources: UN (1992b), except for Korea, Korea (1990) and Taiwan, Republic of China (1991).
5. Nominal Exchange Rate: Units of domestic currency per unit of foreign currency (U.S.$ except for the United States). Source: IFS database (1992).
6. Import Deflator for Intermediate Goods: Source: Latin American countries and Asian countries, World Bank (1992); Korea, Korea (1992); Taiwan, Republic of China (1992); Japan, The Netherlands, France, Germany, the United Kindom and the United States, European Economic Community (1992); rest of the OECD countries, OECD (1992).
7. Inflation Rate: The annual average rate of change of the Consumer Price Index. Source: IMF database (1992).
8. Real Price of Labor: Average manufacturing wage for Argentina, Brazil, Colombia, Chile, Mexico, Venezuela, Korea, Thailand, Malaysia, Hong Kong, Singapore. Other developing countries, average nonagriculture wage. For OECD countries, the real compensation per employee. Deflated by the GDP deflator. Sources: ECLAC (1992), EEC (1992), UN (1992a).
9. Real Price of Imported Materials: For Latin American and Asian countries, nominal exchange rate times dollar price of imported goods divided by GDP deflator. For OECD, implicit deflator for imported intermediate goods deflated by the GDP deflator. Sources: IMF database, EEC (1992).
10. Real Exchange Rate: Nominal exchange rate times a trade-weighted

price index of exported and imported goods divided by the GDP deflator. Source: IMF database (1992).

11. Labor and Capital Shares: Factor shares in GDP are at factor cost net of capital consumption and indirect taxes. Sources: Argentina, Brazil, Chile, Colombia, Mexico and Venezuela, ECLAC (1991). Korea and Taiwan, Korea (1992) and Republic of China (1989), respectively. France, Germany, Japan, The Netherlands, the United Kingdom, the United States, European Economic Community (1992a). Other countries, United Nations (1992).
12. Public and Private Investment: Public investment is investment of general government. Private investment is calculated as the difference between total fixed investment from national accounts and public investment. Sources: OECD (1992) for OECD countries, World Bank (1992) and Pfefferman and Madarassy (1993) for developing countries.
13. Political Variables: PROB is the annual probability of a change in government, estimated by a probit model on time series-data for the period 1948–1982, from Cukierman, Edwards, and Tabellini (1992). ASSASS, CONCHG, CRISIS, REVOL, RIOT, and STRIKE are defined in Tables 5 and 6, and are from Barro and Wolf (1991).

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Comment

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1. Introduction

Robert Pindyck and Andrés Solimano present models of irreversible investment and attempt to provide empirical evidence for the link between uncertainty and investment implied by these models. The potential importance of irreversibility for investment decisions was noted by Arrow (1968); later by Bernanke (1983), Bertola (1987), Pindyck (1988), Dixit (1991), and Bertola and Caballero (1991); and reviewed by Pindyck (1991). The evidence presented here is in two parts, both using aggregate data. The first uses extreme values of profitability as proxies for the threshold rate of profitability and examines the determinants of these thresholds. The second documents that inflation is positively correlated with measures of uncertainty and that inflation is negatively related to investment.

While the theory is convincing that irreversibility is potentially important for investment behavior, I do not find the evidence compelling. Extreme values of profitability are correlated with the variance of profitability even without threshold behavior, so the first tests have no power. While the negative relationship between inflation and investment seems robust, it is not clear what role inflation plays in irreversible investment. The models presented are in real terms, and if inflation is to be a proxy for uncertainty, it is troubling that the standard deviation of inflation is not a better explanatory variable. I propose an alternative explanation for the finding that inflation depresses investment, based on Bernanke's *bad news principle of irreversible investments;* however, the data presented here cannot distinguish this channel from plausible alternatives.

2. *The Theory*

Pindyck and Solimano present two theoretical examples of optimal investment under uncertainty when investment is irreversible. One of their examples examines the decision of whether or not to invest in a project, of the sort examined by McDonald and Siegel (1986). The other model is closely related to a model of firm entry by Caballero and Pindyck (1992). Qualitatively, the same implications can be found in a model like that used by Dixit (1991), where investment is incremental. In that case, the investment decision can be readily compared to that found in models of reversible investment.

Whether investment is thought of as incremental, as projects, or as entry of new firms, the standard prediction of irreversible investment models is that

$$A[\pi_K]^* > p, \tag{1}$$

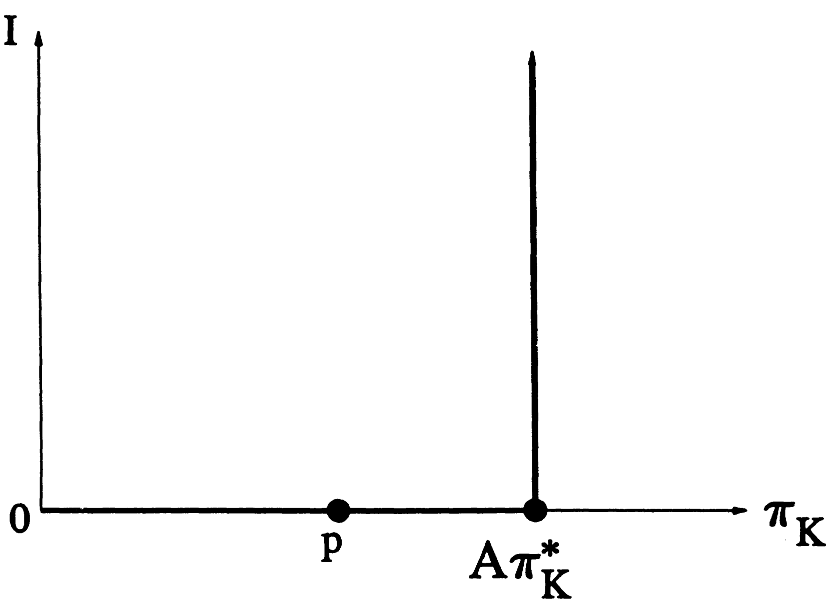
where $A[\pi_K]^*$ gives the marginal profit of capital sufficient to justify investing, and p is the marginal cost of investing. Equation (1) seems in contrast to standard investment models, where firms invest to the point where Equation (1) is satisfied with equality. The apparent difference arises from the nonnegativity constraint imposed on investment by the irreversibility assumption.

Because firms cannot disinvest, they face the possibility of holding "too much" capital. Because of this possibility, the required rate of return that justifies investment is higher. The amount by which it rises depends on how costly it would be and how likely it is that firm would ex post like to disinvest. This value has been called the option value of waiting and rises with uncertainty.

Because the cost of investing is linear, the investment "function" in these models is just a correspondence, as shown in Figure 1. The threshold for investment is $A[\pi_K]^*$, which is strictly greater than p. The difference between the two is interpreted as the option value that is "killed" when investment occurs. The marginal value of additional unit of capital therefore, is, the present value of profits, adjusted by the value of the option that is killed. Equating this marginal value with the marginal cost of investing, p (as in standard investment theories), produces the threshold seen in Figure 1.

Some implications of the model are that the threshold for investment is higher than the marginal cost of investing and that it should increase with uncertainty. Furthermore, over some range, investment should be

Figure 1 THE INVESTMENT CORRESPONDENCE



insensitive to changes in the profitability of capital, but at the threshold it should be infinitely responsive.

3. *Empirics*

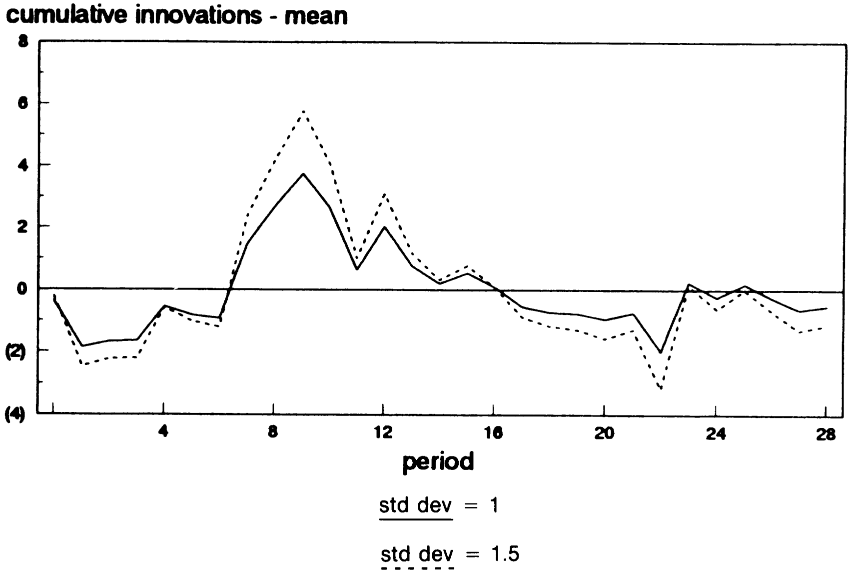
How can the implications of this model be tested? Aggregation is an issue because firms would not be expected to invest simultaneously. One choice would be to estimate directly the investment correspondence in firm-level data, because profitability and investment are observable in principle. To estimate the investment correspondence in aggregate data, one would have to know (or assume) something about the distribution of firms over the range from $[0, A\pi_K{}^*]$. Avoiding this problem, the first section of the paper focuses on the threshold, implicitly assuming that (within country) cross-sectional heterogeneity in this value can be ignored. The second empirical section ignores the aggregation problem and looks directly at aggregate investment.

3.1 TESTS WITH PROFITABILITY

Pindyck and Solimano calculate an aggregate time series for profitability ($b(t)$) for each country in their sample. This series measures average profitability, which in their reference model would equal marginal profitability. In this model, at some threshold level of $b(t)$, call it b^*, firms enter. The threshold b^* is chosen endogenously by firms and depends on the cost of entering, as well as properties of the process for $b(t)$. All of these things are unobservable, but Pindyck and Solimano use several proxies for the threshold and calculate sample moments of $\Delta b(t)$ to measure the drift and standard deviation of the process driving $b(t)$. Their first two proxies for the threshold are the averages of the top decile and the top quartile of observations of $b(t)$ (less the sample mean). They then regress the threshold proxies on the sample moments to examine the determinants of the threshold; the results are reported in their Table 2.

A problem with this procedure, noted by the authors, is that a higher sample standard deviation of $\Delta b(t)$ is consistent with higher extreme values of $b(t)$, regardless of any threshold. In addition, the way the first moment ($\overline{\Delta B}$) is calculated, it could also be negatively affected by extreme values, because the maxima are omitted in calculating $\overline{\Delta B}$. To see these two effects, Figure 2 plots the cumulation of a series of random (normal) innovations. Both lines assume drift of 0.05, while the innovations to the dashed line have a standard deviation 1.5 times that of the solid line. There are two things to note in this example: (1) *DBDEC*, the average of the top three values (the average of observations 8–10 here)

Figure 2 THE EFFECT OF INCREASING VARIANCE



drift = 0.05
DBDEC = 3.03
$\overline{\Delta B}$ = −0.35

drift = 0.05
DBDEC = 4.67
$\overline{\Delta B}$ = −0.54

is larger for the dashed (high variance) line, and (2) $\overline{\Delta B}$ is smaller for the high variance series. Neither of these results is surprising. The average of the top decile of values, *DBDEC*, is a measure of dispersion; when the standard deviation of innovations rises, other measures of dispersion rise as well. $\overline{\Delta B}$ is calculated *omitting the extreme values* used to calculate *DBDEC*; $\overline{\Delta B}$ is therefore the average of changes in $b(t)$, except for its highest values (in levels). If the highest values are associated with large innovations, then omitting these observations will bias downwards the average change.

This example shows that high extreme values may be associated with high sample standard deviations and low $\overline{\Delta B}$ without any threshold behavior. Figure 2 is just an example, so I quantify this effect with a Monte Carlo procedure, applying Pindyck and Solimano's procedure to data drawn from a standard normal distribution. The only restriction is that the coefficient of variation be the same as that in Pindyck and Solimano's data (calculated from the data in their Table 1).[1] The results of this exercise are reported in Table 1.

1. Specifically, the procedure draws a 28 (countries) by 29 (time periods) matrix of normal innovations, with mean variance for each country equal to the country variance ob-

Table 1 MONTE CARLO RESULTS—STANDARD NORMAL DISTRIBUTION, 500 ITERATIONS

Independent variable		*Dependent variable* DBDEC	DBQUINT
Constant	P & S	−0.02	−0.02
		(0.06)	(0.06)
	Random	−0.00	−0.00
		(0.15)	(0.13)
$SD\Delta B$	P & S	3.54	3.23
		(0.63)	(0.57)
	Random	4.09	3.50
		(1.41)	(1.25)
$\overline{\Delta B}$	P & S	−2.15	−3.60
		(1.47)	(1.38)
	Random	−4.73	−4.24
		(1.28)	(1.13)
R^2	P & S	.64	.65
	Random	.51	.51

Rows labeled P & S are from Pindyck and Solimano, Table 2.
Rows labeled Random are from the Monte Carlo procedure.
Standard errors are in parentheses.

The results from the Monte Carlo using the Standard Normal Distribution are qualitatively very similar to those found in Pindyck and Solimano's Table 2. The signs of all the coefficients are the same, and the magnitudes of all coefficients but one are within a standard deviation of each other. These results show that Pindyck and Solimano's results may not reveal a structural relationship between the threshold and the standard deviation and drift of the driving process. Rather, these results may reflect only the statistical properties of the profitability series. Different measures of dispersion are likely to be positively correlated with one another, and drift calculated by omitting extreme values may be lower the higher are those extreme values.[2]

The relationship between the Monte Carlo results and the results

served in Pindyck and Solimano's data. The drift parameter is then chosen to equate each country's coefficient of variation with that in their data. The innovations and drift are then accumulated to obtain series in levels. *DBDEC*, $SD\Delta B$, and $\overline{\Delta B}$ are then calculated from the levels and innovations, respectively, as are the corresponding calculations for the top quintile. *DBDEC* and *DBQUINT* are then regressed on $SD\Delta B$ and $\overline{\Delta B}$. This procedure is repeated 500 times and the coefficients, standard errors, and the R^2 averaged.

2. This implication follows directly if high extreme values are associated with large innovations.

Table 2 MONTE CARLO RESULTS—MIXED DISTRIBUTION, 500 ITERATIONS

Independent variable		*Dependent variable*	
		DBDEC	*DBQUINT*
Constant	P & S	−0.02	−0.02
		(0.06)	(0.06)
	Random	0.03	0.02
		(0.12)	(0.11)
$SD\Delta B$	P & S	3.54	3.23
		(0.63)	(0.57)
	Random	3.71	3.17
		(0.81)	(0.71)
$\overline{\Delta B}$	P & S	−2.15	−3.60
		(1.47)	(1.38)
	Random	−3.91	−3.45
		(1.23)	(1.09)
R^2	P & S	.64	.65
	Random	.64	.63

Rows laeled P & S are from Pindyck and Solimano, Table 2.
Rows labeled Random are from the Monte Carlo procedure.
Standard errors are in parentheses.

reported by the authors can be sharpened by drawing the data from a mixed distribution with "fatter" tails.[3] These results are shown in Table 2.

The estimated coefficients in Table 2 are almost identical to those in Table 2 in the paper (again with the exception of the coefficient on $\overline{\Delta B}$). The Monte Carlo results suggest that the relationship between these "threshold proxies" and the measures of volatility and drift cannot be distinguished from that found in random draws.

The authors also use another threshold proxy, which is the average level of $b(t)$ corresponding to the highest decile or quartile of capital accumulation. In this case, the standard deviation of profitability does not have a significant effect on the threshold proxy, while $\overline{\Delta B}$ continues to have a significant negative effect. This lends further evidence to the view that the relationship between the previous threshold proxies and the standard deviation is just statistical (and not structural)—when the threshold is not an average of extreme values the effect of the standard deviation disappears.

The other cross section evidence reported in the paper relates the

3. This amounts to drawing observations from a normal distribution plus a uniform distribution.

investment–GDP ratio and the real interest rate to these same measures of volatility and drift in profitability ($b(t)$). These results are mixed.

3.2 TESTS WITH INFLATION

The other main empirical point of the paper is that inflation depresses investment. First, Pindyck and Solimano examine determinants of the volatility in profits ($SD\Delta B$) that was the regressor in the previous section. They find that while several measures of political and economic instability are correlated with the standard deviation of profitability, they are all insignificant in multiple regressions when the level of inflation is included. Inflation is the only robust predictor of volatility in profits. Using time series evidence, the paper then establishes a negative relationship between investment–GDP ratios and inflation. The result is robust in their two groups (OECD and LDC) of countries and is stronger when inflation is high.

Why should inflation be negatively correlated with investment? Theory is divided on this point. The Mundell-Tobin effect, e.g., indicates that capital accumulation should rise with inflation. Fischer (1991) and others cite opposing effects, including the effects of inflation on capital taxation, relative price distortions, and fiscal deficits, as well as the relationship between the level and variability of inflation. The irreversible investment models presented by Pindyck and Solimano are silent on this point, because they are in real terms.

The empirical link proposed in the paper is between the volatility of profitability ($SD\Delta B$) and inflation. In the model, increases in the variance of $b(t)$ increase the threshold b^*. As the paper points out, the effect of this change in the threshold on steady-state investment is ambiguous; however, Pindyck and Solimano argue that in the short run, increases in the threshold should be associated with decreases in investment. If we accept this explanation, then if increases in inflation increase the volatility of profitability, the threshold rises, and investment falls.

How can we distinguish the irreversible investment story from other alternatives? The distinguishing characteristic of the link emphasized by Pindyck and Solimano is uncertainty. Uncertainty is typically measured using second moments rather than first moments, so it is disturbing to their story that the level of inflation works better than its standard deviation. Proxies should not have higher explanatory power than the variable for which they are proxying. It would be interesting to examine this issue using the level of inflation as an instrument for its standard deviation—forcing the level of inflation to work via the uncertainty channel.

While it is not proposed by Pindyck and Solimano, there could be a reason why inflation would directly depress investment in an irreversible investment story—if inflation is revealing information about the lower tail of returns to capital. In the models presented by Pindyck and Solimano, stochastic terms enter through geometric Brownian motions. Uncertainty is therefore captured by instantaneous variances, and the empirical equivalents used in the paper are sample second moments. While this is consistent with the model (and the literature), there are at least two problems. First, as the authors note, there could be "peso problems"; uncertainty about some event that has not occurred in sample will not be captured by sample moments. Second, even without peso problems, sample variances may be a poor measure of the relevant uncertainty because of the "bad news principle of irreversible investments," pointed out by Bernanke (1983).

Bernanke notes that with irreversibility, the lower tail of outcomes is particularly important to the investment decision. The value of waiting is determined by how much the firm would be willing to pay to be able to reverse its investment decision. For good states, this value is zero, because the firm would not want to reverse its investment. For bad states, however, this value can be high—and will be affected by changes in the distribution of outcomes over bad states. The good states are irrelevant.

Second moments are, of course, calculated over all states. In symmetric distributions, this is appropriate because "good" realizations are revealing about the lower tail as well. If the distribution of outcomes is asymmetric, however, then information about the good outcomes may provide a biased view of the uncertainty relevant for irreversible investment. In this case, the econometrician needs a measure of the probability and severity of the bad outcomes.

It is difficult to tell if asymmetry of outcomes is important in the data used by Pindyck and Solimano. The average values of profitability growth (in Table 1) are slightly skewed toward negative outcomes, as are the inflation rates graphed in Figures 3–5 of their paper. Certainly the episodes described by the authors fit this pattern. If this is the case, then it may explain why inflation seems to predict investment rates better than its standard deviation. If, as Fischer (1991) says, "a government that is producing high inflation is a government that has lost control" (p. 332), then high inflation may be a proxy for high probabilities of bad outcomes. It is possible to test this speculation rigorously using measures of dispersion that focus on the lower tail. A "peso problem," however, would not be addressed by this approach.

4. Conclusions

Pindyck and Solimano ask a question to which macroeconomists would like the answer. Irreversible investment has been proposed as an explanation for empirical properties of investment that are inconsistent with conventional models. Despite suggestive analytic results, evidence for the irreversibility view has been scarce, and Pindyck and Solimano attempt to provide data to fill this gap. The proxies for the threshold used in the first tests make it impossible to distinguish a structural relationship from a purely statistical one; this method cannot test the implications of the model unless a reliable proxy for the unobserved threshold can be identified. The second set of tests establish that high inflation is associated with lower investment. While this finding does not coincide directly with the models presented here, it is consistent with Bernanke's *bad news principle*—if high inflation is a signal that very bad outcomes are more likely. However, this hypothesis cannot be distinguished from other alternatives based on the evidence provided here. As a result, I remain skeptical but still curious about what irreversibility has to tell macroeconomists about aggregate investment.

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Comment

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Pindyck and Solimano start from the observation that irreversible investment is analogous to an option. Delay is desirable for an option. For example, it is well known that the holder of an American call option on a non-dividend-paying stock should always wait to exercise the option until its expiration, no matter what happens to the price of the stock.

One way the authors characterize this point is that a project has to be unusually good to overcome the value of waiting. To put it differently, the hurdle rate for launching a project must be above the cost of capital. James Poterba and Lawrence Summers (1991) have shown that managers consciously apply hurdle rates above their costs of capital. Poterba and Summers view the finding as confirming that managers are shortsighted, but Pindyck and Solimano provide an alternative explanation based on rational behavior with irreversibility. Neither pair of authors considers another explanation of high hurdle rates, i.e., the winner's curse—random errors in project evaluation will result in systematic selection of overrated projects. Still, the option point is bound to be an important part of the overall story of high hurdle rates.

Taking the option analogy a little further than Pindyck and Solimano do, I think some of the points of the paper can be made by considering a mutual fund that holds a portfolio of call options. The fund books a profit each time it exercises an option. First, the criterion that the fund will use is just as described by Pindyck and Solimano—set a high criterion for current exercise and otherwise wait. Second, if the fund holds options on zero-beta stocks only, so that there is no correlation across options of the events that cause exercise, the fund will earn a constant stream of returns. Its rate of return will be the normal market rate even though it sets a high hurdle for exercise. Absent internal data, we couldn't know about the high hurdle rate or even figure out that there were options at all.

On the other hand, if the mutual fund held positive-beta stocks, we would observe higher returns at those times when the overall stock market was up. These effects would enable the observer to make some inferences about the activities of the fund even from aggregate data for the fund. Pindyck and Solimano face the same challenge, to use aggregate data to make inferences about individual investment options.

As the authors observe, uncertainty has an ambiguous effect on investment. When the payoff of a project is convex in the random disturbance, higher uncertainty makes the project more valuable to the firm, and, therefore, the firm is more likely to undertake the project. On the other hand, the option value of a project rises with uncertainty, and the firm loses the option value when it actually launches a project.

The source of uncertainty receives little attention in the paper, but it seems that it should matter quite a bit. I believe this comment applies both to the theory and to the empirical work. If the technology is such that capital helps deal with uncertain events, then higher uncertainty should unambiguously raise investment. For example, snowmaking equipment is used extensively at ski areas in New England because the weather is so variable. In Colorado, where there is less snowfall but much more predictable weather, snowmaking equipment is less common.

As an empirical measure of the relevant type of uncertainty, Pindyck and Solimano use the marginal product of capital. Their measure is the shadow rental value of capital obtained by solving the factor-price frontier or unit cost function. I can see some hazards in this approach.

First, the measure $b(t)$ is extremely vulnerable to measurement errors in wages and materials prices. The measure is essentially the residual between the product price and input prices, so that measurement errors are magnified substantially—a one percent error in measuring the output price becomes a $1/\beta$ percent error in $b(t)$. Here β is the share of capital in gross output, so $1/\beta$ may be around 6. The cross-sectional relation between investment and measured uncertainty may reflect cross-sectional differences in price measurement error, in part.

Second, the use of wages in the formula requires the strong assumption that wages are the allocation price of labor input. Even in the United States, with few legal restrictions on labor adjustment, much research has disputed the assumption in favor of a wage-smoothing alternative. In the alternative, wages are installment payments on a long-term obligation of employer to worker. The current wage fails to measure the shadow value of labor services just as a mortgage payment does not track the rental value of a house after the mortgage is taken out. Many of the countries in the authors' sample have stringent restrictions on labor adjustment, so wage smoothing is even more likely than in the United States.

Third, the residual calculation relies on the accuracy of the Solow productivity index at cyclical frequencies. Although the reasons for cyclical movements of productivity are controversial, it is a relatively extreme view that the Solow index measures true shifts of the technology over the cycle.

I have already mentioned that the paper tells us little about the fundamental sources of the changes in uncertainty about the marginal product of capital. The section on sources of volatility deals with the correlation of the marginal product and other endogenous variables (inflation, exchange rate, real interest rate, change in government, and various political and social events). The research is limited to a search for correlation with jointly determined variables and does not try to develop a causal chain from exogenous driving forces to uncertainty about the payoff to investment. I am not optimistic that we are likely to make much progress soon on the fundamentals. The only events whose exogeneity is widely accepted are weather and earthquakes, and neither of these has big enough effects to provide much leverage in here or in other research on macro driving forces.

Of the many endogenous indicators of uncertainty considered by the authors, only the mean inflation rate shows strong correlation with the volatility of the marginal product of capital. As the authors note, inflation may be a general indicator of the success of government, or it may be an indicator of the volatility of relative prices in general, or it may have a special effect as a tax on holdings of non-interest-bearing money. Although the paper assembles impressive evidence on the negative correlation of inflation and investment in cross sections of countries, the interpretation of the evidence must necessarily deal in broad generalities. I can't help noting the similarity to research by De Long and Summers (1993), who find a correlation across countries in growth rates and equipment investment. De Long and Summers document that countries with low trade barriers and successful specialization in world markets grow quickly, while those with high barriers and low exports grow slowly. In other words, governments that follow the advice of Adam Smith create prosperity. It appears that Pindyck and Solimano have another finding of the same type: Governments that follow the monetary advice of Milton Friedman are also governments that create favorable environments for investment. Moreover, the propensity to follow the advice of Smith and Friedman is fairly highly correlated across countries, so the two findings are related.

Short-run fluctuations are outside the scope of Pindyck and Solimano's paper, but I continue to believe that the irreversibility of investment should play an important role in fluctuations theory, as Bernanke originally argued. I note that irreversibility is important in the most volatile component of investment, inventory investment, not because the investment itself is irreversible—inventories can certainly be liquidated—but because the creation of inventories through production is irreversible. If we had a theory that explained an increase in uncertainty about the payoff to investment at the beginning of a recession, such that the rational business would defer investment, we would be on our way to a fluctuations theory that came to grips with some important facts about recessions.

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Discussion

Alan Gelb noted that the similarity between the effects of uncertainty on private investment and public investment is somewhat disturbing because the option value model is less likely to apply to public investment. In particular, the fact that inflation enters significantly in the regressions for total investment but not for private investment in the high-inflation sample seems to contradict this prior. Steve Zeldes remarked that the correlation in the high-inflation countries may not be so surprising if the high inflation (and, hence, seignorage financing) signals budgetary problems. In this case, one would expect the government to curtail spending on public investment producing the negative correlation.

Gelb also noted that the thresholds in Figures 3–5 are somewhat arbitrary because they are not known a priori. For example, if the threshold in Figure 3 were 7% instead of 5%, Japan would be below the threshold, and the relationship between inflation and investment would be much less obvious. Solimano agreed that the exact location of the threshold is unclear but argued that the important point of the three figures is that there appears to be a threshold in the relationship between inflation and investment.

Bill English suggested that uncertainty may also affect the composition of investment in addition to the quantity. For instance, some evidence from studies of international direct investment shows that multinationals investing in LDCs that have greater political instability choose capital of shorter durability. He wondered if this effect carries over to the domestic investment in these countries.

Bob Hall remarked that some investments may be undertaken in order to reduce the uncertainty faced by a firm and cited the example of snowmaking equipment at New England ski areas. Olivier Blanchard wondered if this were a unique example and suggested that advertising expenditures may operate in much the same way, reducing the uncertainty in demand faced by a firm with a new product.

Finally, David Romer expressed concern about measurement issues and the effects of inflation. Perhaps it is not surprising that when one computes the marginal product of capital as a residual in a country with very high inflation, one finds that the variability of this measure is related to average inflation. Solimano responded that measurement problems are certainly important, but noted that this is why the authors also examined semi-reduced form estimation such as the regression of investment rates on inflation rates.