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PRICE UNCERTAINTY AND INVESTMENT BEHAVIOR OF CORPORATE MANAGEMENT UNDER RISK AVERSION AND PREFERENCE FOR PRUDENCE

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Abstract

The current paper reconsiders the theory of corporate investment under price uncertainty. The assumption that management is a perfect, risk-neutral agent of corporate owners has been relaxed. It is found that the management's limited opportunity to diversify and limited ability to finance consumption by borrowing against human capital creates a mechanism which reinforces the technology effect discussed in the earlier literature calling for more current capital investment essentially functions as a precautionary mechanism for risk-averse management with a preference for prudence in conditions of imperfect spanning. The result is likely to hold under diminishing absolute risk aversion and a diminishing preference for prudence when the management participates in sharing corporate risks. The model can be viewed as marrying the neoclassical theory of investment with the managerial theory of a firm. Its key assumption is the separation of ownership and control in the sense that the that the shareholders are considered to be unable to evaluate investment projects while the management is.

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I Introduction

The role of price uncertainty in determining a firm's investment decisions has attracted a great deal of research interest. It was more than 20 years ago that Sandmo (1971) suggested in his now classic work that price uncertainty makes a competitive firm produce less output than a firm operating under price certainty would produce. Subsequently, however, this result was challenged by Hartman (1972) and Abel (1983) who showed that for a firm operating under constant returns and convex costs of adjustment, increased uncertainty of future prices implies more capital demand today.[1] The Hartman and Abel result is counterintuitive. It is now known that the result can be reversed with decreasing returns (Hartman (1973)) imperfect competition (Caballero (1991)) and with irreversible investment (Pindyck (1991)). It was also hinted by Hartman (1976) that risk aversion would reverse the result.

The current paper reconsiders the predictive value of the above results which have all been derived on the assumption that corporate managers are perfect and risk-neutral agents of the shareholders. This seems a problematic starting point when it comes to examining the effects of uncertainty. Recall that Sandmo (1971) and Hartman (1976) also made attempts to analyze the effects of risk aversion. However, their models can perhaps best be interpreted as descriptions of an owner-managed firm, so that their generality may be rather limited in that modern firms are typically run by hired management with selfish targets, monitored weakly by the shareholders and with limited ability to diversify their human capital in the context of imperfect spanning.[2]

It thus seems important to raise the question of whether can the earlier results survive when the assumption of a firm's value-maximizing risk-neutral, perfect management is replaced by a risk-averse management with its own targets. Moreover, imperfect spanning means limited access to insurance against income risk. Hence, in light of the finding that the preference for prudence has since Leland (1968) been seen as important for behavior under uncertainty, there is good reason to explore in what way the management's preference for prudence may enter into the investment analysis. By the introduction of management behavior, this paper will suggest a marriage between the neoclassical theory of investment and the managerial theory of a firm.

The introduction of management risk aversion and prudence turns out to be technically quite hard.[3] The principal agent models have earlier suggested that owners can be expected to construct an appropriate incentive scheme. We study the implications of a class of such compensation schemes, taken to be linear. The possibilities of solving for the effects of price uncertainty on investment turn out to depend on what restrictions one finds it legitimate to impose on the information set of the stockholders. We provide such a set of constraints which are rather natural. The key assumption is the way in which we introduce separation of ownership and control: the shareholders are assumed to be unable to formulate the investment program of the firm of which they are owners.[4] As to the technology, the assumption of constant returns is introduced. Interestingly, the preferences need not be strictly parametrized to obtain the solution.

The payoff of our extension to the prevailing theory includes some important results. We first show that under an indepedent management, there typically is an overinvestment incentive. It has been suggested earlier that risk aversion and incomplete markets are likely to make the investment-uncertainty relationship negative. Against our expectations, however, we show that this intuition goes wrong when a firm is run by risk averse management with a preference for prudence. What matters for optimal revision of an investment program under increased output price uncertainty is the relative share of non-risky and risky income in the management's reward structure. Under plausible hypotheses of decreasing absolute risk aversion and decreasing preference for prudence, current investment may decrease when management's income is hedged by a fixed income. However, when there is less of such hedging, we show that it is best to increase current investment. This result follows because the management's limited opportunity to diversify and finance consumption by borrowing against human capital creates a precautionary mechanism which enforces the technology effect discussed earlier and calls for more current capital investment. Capital investment provides a precautionary strategy for prudent risk-averse management.[5]

II Assumptions and Optimality Condition

We consider a share company and assume that investment planning is complex enough to require special competence. We assume that some agents, called managers, have access to the

required skill while the outside shareholders do not and hence confine themselves to trading the firm's shares. Informational asymmetries reduce the owners' ability to monitor the managers. In particular, we assume that the shareholders are at best imperfectly informed about the true preferences of the managers.[6] This has the important implication that the shareholders are unable to formulate the optimal investment rule. This justifies the view that their best response is to take the management's announcement of future investment policy as given.

The above informational constraint represents a vital departure from the starting point of the previous work cited in the introduction where management has been taken to be a perfect risk-neutral agent of the owners. We do, however, provide the shareholders with the following information: the shareholders understand that the production technology is characterized by constant returns.

The conflict of interest introduced by the current paper is well-known and may arise in a number of ways.[7] In their study on performance pay and top-management incentives, Jensen and Murphy (1990) write: "Managerial actions and investment opportunities are not perfectly observable by shareholders; indeed, shareholders do not often know what actions the chief executive officers *can* take or which of these actions will increase shareholders' wealth. They claim that the CEO compares only his private gains and cost from pursuing a particular activity.[8]

Let us denote the firm's short-run profit function, strictly convex in its output price p, by $pk\pi(p)$, which follows from the assumption of constant returns. The price p is assumed to follow a geometric Brownian motion, $dp_t/p_t = \sigma dz_t$, where dz_t is the increment of a Wiener process with $\sigma^2 > 0$ as its variance rate.[9] Let V denote the current stock market price of the firm's shares. We assume that the owners have decided upon the management compensation (m_t) in terms of observed corporate performance. The labor contract delegates the investment policy to the managers. We investigate the implications of a linear but otherwise a rather general management remuneration scheme of the form

$$(1) \quad m = \psi_o + \psi_1 pk\pi(p) + \psi_2 V, \quad \psi_o > 0,\ \psi_1 > 0,\ \psi_2 > 0.$$

We do commonly find linear schemes in the real world. Scheme (1) provides at most a partial hedge (ψ_o) for management against income risk. There is thus a certain degree of risk-sharing between the owners and the management. Moreover, the management is constrained by the fact that its current policy not only interacts with its current reward (through ψ_2) but also the future rewards (through ψ_1 and ψ_2). Clearly, myopic behavior cannot be expected to be optimal, even though we have no plans to introduce any costs of adjusting corporate capital in the model.

Use D to denote the flow of dividends to the owners, $D(k,p) = pk\pi(p)-j-m$, where j = the current rate of investment, $jdt = dk$, and introduce the owners' capital market opportunity cost, say r. The standard asset pricing assumption then gives the valuation of corporate shares in the stock market as

$$(2) \quad V(k_t,p_t) = E_t\int_t^{\infty} e^{-r(\tau-t)}D(k_\tau,p_\tau)d\tau,$$

where E_t is an expectations operator, conditional on all information acquired by the owners through to time t. The owners know that from each unit of current profit, fraction ψ_1 is paid out to the management. They also know that fraction ψ_2 of a change in the stock price is absorbed by the management. This must then affect the effective discount rate of the owners. Indeed, using the relationship

$$k_\tau = k_t + \int_t^{\tau} j_s ds, \quad s \geq t,$$

and Fubini's theorem, it is convenient to rewrite (2) as

$$(3) \quad V(k_t,p_t) = \frac{-\psi_o}{r+\psi_2} + \left(\int_t^{\infty} e^{-(r+\psi_2)(\tau-t)}E_t[(1-\psi_1)p_\tau\pi(p_\tau)d\tau]\right)k_t +$$

$$\int_t^{\infty} e^{-(r+\psi_2)(\tau-t)}E_t\left[\left(\int_\tau^{\infty} e^{-(r+\psi_2)(y-\tau)}E_\tau((1-\psi_1)p_y\pi(p_y))dy-1\right)j_\tau\right]d\tau.$$

One should emphasize that in (3), shareholders do not regard the flow $\{j_\tau\}$ as the choice variable: they consider it parametric. Equation (3) is the value of the firm under any announced investment program, decomposed as between the present value of income from capital accumulated so far, k_t, and the cash flow from the future investment program, whatever it might be. Note that, given the investment program, $V_{kp} > 0$, $V_{kpp} > 0$; V_k is convex in price.[10] This just repeats the idea that corporate shares replicate a call option for their owners.

We now explicitly introduce the assumption that the firm is run by a risk-averse management. Assume that $u(m)$ is the management's utility function with $u' > 0$, $u'' < 0$, $\lim_{m \to 0} u'(m) = \infty$ with $A(m) = -u''(m)/u'(m) > 0$ as the measure of absolute risk aversion and $P(m) = -u'''(m)/u''(m) > 0$ as the Kimball (1990) measure of (absolute) prudence.[11] It holds for most plausible utility functions that $P(m) > 0$. Moreover, we assume that the human capital of management cannot be diversified due to imperfect spanning in assets markets, nor is the management engaged in capital market transactions. In the absence of spanning,[12] we introduce a positive discount rate for management, say α, stay loyal to the expected utility hypothesis and write the intertemporal (separable) utility as

$$(4) \quad J(k_t,p_t) = \max_j E_t\int_t^{\infty} e^{-\alpha(\tau-t)}u(m(k_\tau,p_\tau))d\tau.$$

In the current paper, we thus consider the investment program which maximizes the management utility (4), not that which maximizes the value of the firm's shares (2).

It is clear by now that the approach we have introduced is much more complicated in terms of management-owner interaction than that has been offered by the more traditional neoclassical models. Not surprisingly therefore, it is more difficult to predict what the solution to our problem will be. Yet, as we will show, the complication we have introduced will provide a good payoff in terms of new results. To obtain these results, however, the informational assumptions introduced above need to be fully exploited.[13]

In particular, since the owners are taken to be unable to judge which investment program is optimal for the managers, their best response is to take the announced investment program as given and, because of constant returns, regard the market value of shares as linear in capital. It is hence rational for the shareholders to assume that $V_k > 0$ and $V_{kk} = 0$. It also follows that $V_{kj} = 0$, because the owners consider the marginal valuation of capital independent of the amount of capital. However, unlike the traditional theory in which $V_j = 0$ by the optimality condition, here the value of V_j has to be evaluated.

An investment program which maximizes the management's utility (4) has to satisfy the Hamilton-Jacobi-Bellman equation

$$(5) \quad \alpha J(k,p)dt = \max_j u(m(k,p;j))dt + E_t(dJ)$$

where the gain to the current investment decision is decomposed in the spirit of dynamic programming as between current utility and the expected gain in terms of the discounted future utilities. Using Ito's lemma, the latter effect can be re-written as

$$(6) \quad (1/dt)E_t(dJ) = jJ_k + (\frac{1}{2})p^2\sigma^2 J_{pp}.$$

Here J_k is the conditional expectation of the value of all future utility gains from the marginal capital. Then any candidate for the optimal control has to satisfy the following first-order condition

$$(7) \quad u'\psi_2 V_j + J_k = 0.$$

One should pause at this condition to pay attention to the way the management-owner interaction shows up: both valuations V and J enter the first-order condition.

III Investment Incentives

We will now establish the condition for the existence of a finite unique investment program in terms of project profitability. The asset pricing (4) creates a constraint for the management's maximization problem. It is, however, in an integral form. To cope with this technical diffituly, it is most helpful to re-write it. Over a short time interval, the asset holders value their shares according to (cf. Dixit and Pindyck (1994))

$$(8) \quad V(k_t,p_t) = D_t dt + e^{-rdt}E_t(k_t+dk,p_t+dp).$$

We have suppressed the flow of investment j from valuation $V(k,p)$ for the reason that it is the strategic variable of the management but parametric for the asset holders. From (8) Ito's Lemma yields

$$(9) \quad (1/dt)E_t(V(k+dk,p+dp)-V(k,p)) = jV_k + (1/2)V_{pp}p^2\sigma^2.$$

Then, from (8) and (9), the market value V satisfies the partial differential equation

$$(10) \quad V(k,p) = [(1-\psi_1)k\pi(p)-j-\psi_o+jV_k+(\frac{1}{2})V_{pp}p^2\sigma^2]/(r+\psi_2).$$

Differentiating with respect to *current* investment j_t, one finds that the impact of the investment program on share value is obtained as the present value

$$(11)\quad V_j = \frac{V_k - 1}{r+\psi_2}.$$

Note that in Abel's model, V_j has to be zero by the principle of optimality. The rather natural interpretation of (11) is that the asset holders compare the discounted costs of investment program against discounted future returns. The opportunity cost for shareholders of *$1* corporate investment is $\$1/(r+\psi_2)$, allowing for the foregone interest while the total gain from higher capital stock is given by $\$V_k/(r+\psi_2)$.

It is helpful to rewrite the first-order condition (7) as

$$(12)\quad u'(m(j)) = -\frac{J_k}{\left(\frac{\psi_2}{r+\psi_2}\right)(V_k-1)}.$$

where the right-hand side is independent of j. Differentiating (5) with respect to state k, making use of the transversality condition $lim_{t\to\infty}\, e^{-\alpha t}J_k(k,p) = 0$ and using Fubini's theorem allows us to solve for the marginal valuation of capital

$$(13)\quad J_k(k_t,p_t) = \int_t^\infty e^{-\alpha(\tau-t)}E_t[u'(m(\tau))m_k(\tau)]d\tau.$$

This clearly is always positive as is the marginal utility on the left-hand side of (12), $u'(m(j)) > 0$. Two potentially interesting cases may then arise. From time to time, some management may come up with an exceptional idea, a "gold mine" with $V_k > 1$, hence $V_j > 0$. In the framework of our model, it would then pay to expand capital at the maximum rate. Optimal current investment would be infinite and we would not be in the world of an internal optimum.[14] Most typically, however, the investment projects available are not "gold mines" but ones with more limited profitability. In such a case, the management will consider balancing between the trade-off of a current reduction in asset values due to undertaking such a program and the expected future gains from larger capital over the longer run. There will

be a finite optimal current investment level even in the absence of costs of adjustment or decreasing returns. Such a case is characterized by the condition $V_k < 1$ in (12) which is the condition for an interior optimum.[15] The second-order condition $u''(m)m_j^2 < 0$ is then also satisfied; from (11) $V_{jj} = 0$. Suppose that the price falls so low that the management prefers disinvesting. Even in that case, the management prefers the capital declining at a lower rate than desired by the owners. For positive growth, sufficient management compensation, however, is required. It is easy to establish that $m(j)|_{j=0} > (u')^{-1}(-J_k/m_j)$ is a sufficient condition for optimal j to be positive. What is hence so surprising is that even though we exclude the "gold mine" projects, the corporation is still left with a systematic overinvestment incentive:

Proposition 1. ***For a rational manager with a concave utility funtion $u'(m) > 0$, $u''(m) < 0$ and equipped with a management compensation scheme (1), even when there is unique finite optimal investment program, the manager has a systematic over-investment incentive in the sense that it is optimal to adjust capital so as to make its marginal value for the shareholders fall short of the marginal cost of investment.***

Proposition 1 hence provides an explicit description of the management-owner interest conflict under separated ownership and control.

IV Price Uncertainty

We have established above that when the firm grows, the optimal rate of investment depends upon the current price of output and the uncertainty about future prices. Then conditions (12) and (13) suggest that the effects of price uncertainty depend both on the convexity of V and V_k and the possible convexity of $u'(m)m_k$ in price through the Jensen's inequality. It is clear that the convexity of $u'(m)m_k$ is related to the preference for prudence and risk aversion. Below we are able to characterize the optimal investment behavior in terms of management preferences even without trying to find the explicit solution for the unknown value function $J(k,p)$.

To derive the investment equation in terms of management preferences and asset pricing, we start by eliminating the unknown value function J from the first-order condition.

Differentiating the Hamilton-Jacobi-Bellman equation with respect to the state variable k gives a version of the Euler-equation

$$(14) \quad \alpha u'\left[\frac{\psi_2(1-V_k)}{r+\psi_2}\right] = u'[\psi_1 p\pi(p)+\psi_2 V_k]+\frac{1}{dt}E_t dJ_k(k,p).$$

Then eliminate the last term using Ito's lemma and insert

$$(15) \quad J_{kp} = \frac{\psi_2}{r+\psi_2}[u''(1-V_k)m_p-u'V_{kp}]$$

$$(16) \quad J_{kpp} = \frac{\psi_2}{r+\psi_2}[u'''(1-V_k)m_p^2-2u''V_{kp}m_p+u''(1-V_k)m_{pp}-u'V_{kpp}].$$

Then, solving the Euler-equation for j, we arrive at a convenient expression for the current investment as

$$(17) \quad j = \left(\frac{1}{\eta_o}\right)[\eta_1+\eta_2\sigma^2]$$

where

$$\eta_o = \left(\frac{1}{r+\psi_2}\right)(1-V_k)m_k > 0, \quad \eta_1 = \left(\frac{1}{A}\right)\left[\psi p\pi(p)+\frac{(\alpha+r+\psi_2)V_k-\alpha}{r+\psi_2}\right] > 0,$$

$$\eta_2 = \left(\frac{1}{2}\right)\left(\frac{1}{r+\psi_2}\right)\left[(1-V_k)(P(m)m_k^2-m_{pp})+2m_pV_{kp}-\frac{1}{A(m)}V_{kpp}\right]p^2$$

and where $\psi = \psi_1/\psi_2$.

The first effect in (17), η_1/η_o, is (to be strict, under a very mild assumption) positive, reflecting the view advanced above that the management has an incentive to let capital expand. Optimal investment, though positively related to current and future profitability, is inversely related to the measure of concavity of the utility function, $A(m)$. This mechanism on optimal investment operates even in the absence of price uncertainty. That current investment is positively related to the value of V_k, the shadow price of capital for the owners through the η_1/η_o term, is also a prediction by those models where the management stands ready to maximize the market value of shares. However, even large unexpected price shocks resulting in revaluation of V_k give rise only to small changes in investment through the η_1/η_o effect if A(m) is "great" since diminishing utility tends to stabilize behavior. Moreover, under hired management, this relationship is influenced both by r and α, through η_1/η_o. It is, however, the discount rate of the management which negatively affects current investment demand. As far as the management compensation structure is concerned, the partial effect on current investment operating through short-run profits becomes more important under large ψ_1/ψ_2.

Move to the second term, the uncertainty effect proper, $(\eta_2/\eta_o)\sigma^2$. Suppose that there is a small mean-preserving spread in price starting with $\sigma^2 = 0$. Then it is *the sign of* η_2 which is informative as to the uncertainty effect. Though η_2 is rather involved, some conclusions are readily at hand. While the coefficient of absolute risk aversion $A(m)$ helps to study the impact of uncertainty on expected utility, the coefficient of preference for prudence $P(m)$ helps to study the impact of uncertainty on the expected marginal utility (hence on J_k). Note first that $2m_pV_{kp} > 0$ always. It is, however, not necessarily the case that increased price uncertainty induces the management to invest more. For example, take for the sake of illustration the case of quadratic utility with $P(m) = 0$ and low $A(m)$. Such a management would find it best to respond by currently investing less with increased price uncertainty. Even if $P(m)$ is positive, the term $P(m)m_k^2 - m_{pp}$ in η_2 may take either sign. It is, however, definitely positive when $P(m)$ is sufficiently large. This effect is reinforced when $A(m)$ is sufficiently large, too.

It is helpful to recall that the management reward consists of safe (through ψ_o) and risky (through ψ_1 and ψ_2) income. Let us introduce the plausible hypotheses of decreasing absolute risk aversion and decreasing preference for prudence. Though the relative shares of non-risky and risky income depend upon how the output price evolves, one is likely to have low $A(m)$ and low $P(m)$ when ψ_o is relatively high providing high insurance. Conversely, when the share of risky income is greater, the management is likely to increase the current investment when the output price uncertainty is increased. Therefore, the extent to which the management takes part in sharing risks with the stockholders is essential for the optimal management response to increased price uncertainty.

We have

Proposition 2. ***Under the type of compensation scheme (1) with sufficient management risk sharing, increased uncertainty (in the mean-preserving sense) of future prices induces corporate management to increase current investment in capital.***

Note that $P(m)$ an $A(m)$ operate somewhat asymmetrically in the model since $A(m)$ enters both terms in (17) while $P(m)$ enters only the second one.

Increased uncertainty involves the management becoming more prudent. It finds it best to expand capital investment in the short run. The intuition for this result is as follows: it is optimal to cause a decline in current share prices and hence in current remuneration in exchange for higher consumption in the future. While greater price uncertainty makes the stock price and management remuneration more volatile, a current increase in capital investment provides the manager with an instrument for precautionary strategy. Though there is no safe asset for the management, there is a kind of insurance effect: *capital investment functions as a precautionary mechanism for risk-averse, prudent management.* Note moreover that the uncertainty effect η_2/η_o is independent of the management's discount rate α. Moreover, the prudence effect on investment decisions depends positively on m_k^2, the impact of corporate assets on management compensation. We want to point out one additional result: the total effect of the owners' required rate of return (r) on optimal investment undertaken by the management is highly ambiguous. This may be a somewhat disappointing result for those working with the more traditional neoclassical models.

To sum up,

Proposition 3. ***The optimal current investment of the management depends positively on the marginal shadow price of capital for the owners but negatively on the discount rate of the management.***

Concluding Comments

The issue of corporate investment has attracted a great deal of attention in the previous literature. The current paper has reconsidered this issue by showing that when the assumption of management as a perfect agent of corporate owners is relaxed, some relevant new mechanisms are introduced. Interestingly and somewhat counterintuitively, it is not the case that management risk-aversion would necessarily change the conclusion obtained earlier, i.e. that increased price uncertainty would enhance corporate investment incentives. What is true is that the management's limited opportunity to diversify and finance consumption by borrowing against human capital creates a precautionary mechanism which enforces the technology effect discussed earlier, and calls for more current capital investment. The magnitude of this effect is related to the way in which the management remuneration has been constructed. While capital investment functions as precautionary mechanism for prudent risk-averse management, it may be possible to qualify the analysis in the case the management would have access to some insurance mechanism, say through capital market investment. A likely case would be that the possibility of insuring might run against the precautionary mechanism outlined in the current paper.

Footnotes:

1. This result follows from Jensen's inequality and holds in a model where the firm can adjust variable inputs after observing the current price, provided that substitutability between factors is sufficiently easy, cf. Hartman (1976). While Hartman's conclusion was derived under any price distribution, Abel (1983) verified it under a particular price process (the geometric Brownian motion) arriving at the explicit optimal investment rule. Though it is a natural result that under constant returns a firm's value is linear in capital, Abel managed to solve explicitly for a firm's equilibrium valuation and its relation to price uncertainty.

2. In Tirole's (1989 p.34) words : "It is a postulate...of most economic theory, that firms maximize expected profits. There is, however, a widespread feeling that in practice firms' managers have other objectives."

3. As fas as I am aware, the control problem of the current paper including a forward-looking integral constraint has not been studied earlier in the literature.

4. Allowing the stockholders to be better informed about what is going on within the firm's investment planning process would complicate the mechanisms and hence make the analytic solution much harder, if not impossible, to obtain.

5. Our results about the overinvestment incentive can be viewed as providing one explanation for some well-known earlier views which have emphasized sales or growth maximization of a capitalistic firm under separated ownership and control.

6. The assumption that knowledge of preferences is private infomation is a natural assumption though it is a stricter constraint than the one introduced by the early principal agent models.

7. Cf. Holmstrom and Ricart I Costa (1986) for a model emphasizing career concerns.

8. Haubrich (1994) argues that the Jensen and Murphy results match the principal-agent theory. Narayanan (1985) finds that when a manager has private information regarding his decisions, he has incentives to make decisions which yield short-term profits but are not in the stockholders interests. Kaplan (1994) summarizes the recent dispute on whether Japanese managers maximize the firm's growth instead of the share price.

9. Recommended reading on the mathematical background of stochastic calculus includes the excellent works by Pindyck (1991) and Dixit and Pindyck (1994).

10. Abel (1983) derived the explicit expression for V_k in terms of price variance under the Cobb-Douglas production technology.

11. It may be helpful to recall that the preference for prudence is related to the precautionary behavior, reflected in the convexity of the marginal utility. The role of condition $u''' > 0$ in generating more prudent behavior in the case of uncertainty was first derived by Leland (1968), who showed that risk aversion alone is insufficient to guarantee a precautionary demand for saving. The equivalence between the sign of u''' and an individual's preference

for or aversion to downside risk was established by Menezes, Geiss and Tressler (1980).

12. For techniques of dynamic programming when spanning does not hold, see Dixit and Pindyck (1994).

13. One way to view our approach is to regard the owners as "followers" who take the management's strategy as given. Management, in turn, is a "leader" who understands the market's reaction to the announced investment policy through share valuation. The ability of the owners fully to understand the determination of the investment program would complicate the decision problem of the management considerably. It then should also be optimal for the management to take account of the potential feedback effects from current capital to current investment. Such a case does not lend itself to an analytic solution. If the shareholders, however, had access to such an ability with perfect monitoring, the need to hire an outsider management would disappear.

14. Introduction of convex adjustment costs, irreversibility of investment, or alternatively, decreasing returns to capital, would provide a finite investment program along the optimal path even in such a case.

15. We should point out that the case $V_k < 1$ is no limitation on generality. It covers even the case where the marginal gross return exceeds the cost of capital, $p\pi(p) > r$, but where it is the management compensation which turns the inequality into $p\pi(p) < (r+\psi_2)/(1-\psi_1)$

References:

Abel, Andrew B., "Optimal Investment under Uncertainty," *American Economic Review*, March 1983, 73, 228-33.

Caballero, Ricardo J., "On the Sign of the Investment-Uncertainty Relationship," *American Economic Review*, March 1991, 81, 279-88.

Dixit, Avinash and Pindyck Robert S., *Investment under Uncertainty,* Princeton: Princeton University Press, 1994.

Hartman, Richard, "The Effects of Price and Cost Uncertainty on Investment", *Journal of Economic Theory*, 1972, 5, 258-66.

Hartman, Richard, "Adjustment Costs, Price and Wage Uncertainty, and Investment", *Review of Economic Studies*, 1973, 40, 259-67.

Hartman, Richard, "Factor Demand with Output Price Uncertainty", *American Economic Review*, September 1976, 66, 675-81.

Haubrich, Joseph G., "Risk Aversion, Performance Pay, and the Principal-Agent Problem", *Journal of Political Economy*, 1994, 102, 258-76.

Holmstrom, Bengt and Joan Ricart I Costa, "Managerial Incentives and Capital Management", *Quarterly Journal of Economics*, November 1986, 835-60.

Jensen, Michael C. and Murphy, Kevin J., "Performance and Top-Management Incentives", *Journal of Political Economy*, 1990, 98, 225-64.

Kaplan, Steven N., "Top Executive Rewards and Firm Performance: A Comparison of Japan and the United States", *Journal of Political Economy*, 1994, 102, 510-46.

Kimball, M.S., "Precautionary Saving in the Small and in the Large", *Econometrica*, January 1990, 58, 53-73.

Leland, Hayne E., "Saving and Uncertainty: The Precautionary Demand for Saving", *Quarterly Journal of Economics*, 1968, 82, 456-73.

Menezes, C., Geiss, C., and Tressler J., "Increasing Downside Risk", *American Economic Review*, 70, 1980, 921-32.

Narayanan, M.P., "Managerial Incentives for Short-Term Results", *The Journal of Finance*, 1985, XL, 1469-84.

Pindyck, Robert S., "Irreversibility, Uncertainty, and Investment", *Journal of Economic Literature*, 1991, XXIX, 1110-48.

Sandmo, A., "On the Theory of the Competitive Firm Under Price Uncertainty", *American Economic Review*, 1971, 61, 65-73.

Tirole, Jean, *The Theory of Industrial Organization,* Cambridge: The MIT Press, 1989.

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