Irreversibility and the Explanation of Investment Behavior

by

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ABSTRACT

The explanation of aggregate and sectoral investment behavior has been one of the less successful endeavors in empirical economics. Existing econometric models have had little success in explaining or predicting investment spending. This may be because most such models fail to account for the irreversibility of most investment spending. With irreversibility, changes in the riskiness of future cash flows or interest rates should in theory dramatically affect the decision to invest -- more so than, say, a change in the levels of interest rates. Here I survey some of the empirical support for this proposition, and discuss the implications for investment modelling.
IRREVERSIBILITY AND THE EXPLANATION OF INVESTMENT BEHAVIOR

1. Introduction.

The explanation of aggregate and sectoral investment behavior has been one of the less successful endeavors in empirical economics. Existing econometric models have simply not been very good at explaining or predicting investment spending. The problem is not just that these models have been unable to explain and predict more than a small portion of the movements in investment. In addition, constructed quantities that in theory should have strong explanatory power -- e.g. Tobin's q, or various measures of the cost of capital -- in practice do not, and leave much of investment spending unexplained.¹

It is easy to think of reasons for the failings of these models. For example, even leaving aside problems with their theoretical underpinnings, there are likely to be formidable estimation problems resulting from aggregation (across firms, and also across investment projects of different gestations). I will not attempt to survey these problems here, nor in any way provide a general overview of the state of investment modelling. Instead I want to focus on one special aspect of investment - the role of risk, and in particular the effects that risk has on investment when expenditures are irreversible.

Most major investment expenditures have two important characteristics which together can dramatically affect the decision to invest. First, the expenditures are largely irreversible; the firm cannot disinvest, so the expenditures are sunk costs. Second, most major investments can be delayed. Hence the firm can wait for new information to arrive about prices, costs, and other market conditions before it commits resources.
Irreversibility usually arises because capital is industry or firm specific, i.e., it cannot be used productively in a different industry or by a different firm. A steel plant, for example, is industry specific. It can only be used to produce steel, so if the demand for steel falls, the market value of the plant will fall. Although the plant could be sold to another steel company, there is likely to be little gain from doing so, so the investment in the plant must be viewed as a sunk cost. As another example, most investments in marketing and advertising are firm specific, and so are likewise sunk costs. Partial irreversibility can also result from the "lemons" problem. Office equipment, cars, trucks, and computers are not industry specific, but have resale value well below their purchase cost, even if new. In this case, at least a portion of the initial investment is a sunk cost.

When investments are irreversible and can be delayed, the decision to invest becomes extremely sensitive to uncertainty over future cash flows. In the next section I summarize the reasons why this is the case. This summary is quite brief, and largely refers to the literature on "real options" that has emerged on this topic during the past few years. A much more detailed summary and explanation of the analysis of irreversible investment can be found in my recent survey paper (1990). Here my focus is on the empirical modelling of investment (and the need for better empirical studies). Do risk and irreversibility interact in affecting investment behavior the way theory says they should? Sections 3 and 4 discuss empirical issues, and summarize two studies (one of which is mine) that represent the small amount of evidence on this question that I am aware of. Section 5 briefly discusses future research and concludes.
2. Implications of Irreversibility.

Non-diversifiable risk plays a role in even the simplest models of investment, by affecting the cost of capital. But there is an emerging literature that suggests that risk may be a more crucial explanator of investment. The thrust of this literature begins with the fact that much of investment spending is irreversible and can be delayed. In this case, the standard net present value method that evaluates an investment by comparing its cost to the present value of the cash flows it is expected to generate does not apply.

Instead, the investment expenditure can be viewed as analogous to the exercising of an option (an option to productively invest). Once such an option is exercised, it is "dead," i.e. one cannot decide to exercise it instead at some point in the future, or never at all. Specifically, one gives up the option of waiting for new information (about evolving demand and cost conditions), and using that information to re-evaluate the desirability and/or timing of the expenditure.¹ This lost option value must be included as part of the cost of the investment. Doing so leads to an investment rule that can be viewed as a modified net present value rule: "Invest when the value of a project is at least as large as the direct cost of the project plus the opportunity cost of exercising the option to invest." In other words, the value of the project must exceed the cost by an amount equal to the value of keeping the firm's option to invest alive.²

Recent studies (see the references in Footnote 2) have shown that this opportunity cost can be large, and investment rules that ignore it can be grossly in error. Also, this opportunity cost is highly sensitive to uncertainty over the future value of the project, so that changing economic conditions that affect the perceived riskiness of future cash flows can have
a large impact on investment spending, larger than, say, a change in interest rates. (In the context of macroeconomic policy, this means that if the goal is to stimulate investment, stability and credibility may be much more important than tax incentives or interest rates.)

The dependence of investment on interest rates provides an interesting example of the implications of irreversibility. Interest rates are key variables in traditional econometric models of investment, but they are often found to be statistically insignificant when those models are estimated. In a recent paper, Ingersoll and Ross (1988) examined irreversible investment decisions when the interest rate evolves stochastically, but future cash flows are known with certainty. 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. Also, the difference between $r^*$ and $r^0$ grows as the volatility of interest rates grows.

Ingersoll and Ross also show 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. This shows how the level of interest rates may be of only secondary importance as a determinant of aggregate investment spending. Interest rate volatility (as well as the volatility of other variables) may be more important.

As another example, consider the recessions of 1975 and 1980. The sharp jumps in energy prices that occurred in 1974 and 1979-80 clearly contributed to those recessions. They caused a reduction in the real
national incomes of oil importing countries, and they led to "adjustment effects" -- inflation and a further drop in real income and output resulting from the rigidities that prevented wages and non-energy prices from coming into equilibrium quickly. But those energy shocks also caused greater uncertainty over future economic conditions. In particular, it was unclear whether energy prices would fall or continue to rise, what the impact of higher energy prices would be on the marginal products of various types of capital, how long-lived the inflationary impact of the shocks would be, etc. Other events also made the economic environment more uncertain, especially in 1979-82 in the United States: much more volatile exchange rates and interest rates. This may have also contributed to the decline in investment spending that occurred during these periods. 5


As I suggested at the outset of this paper, the irreversibility of most investment expenditures, and the implications that irreversibility has for risk, may help to explain why neoclassical investment theory has failed to provide good empirical models of investment behavior. Effects of risk are typically handled by assuming that a risk premium (obtained, say, from the CAPM) can be added to the discount rate used to calculate the present value of a project. But as we have learned from financial option pricing and its application to real investment, the correct discount rate cannot be obtained without actually solving the option valuation problem, that discount rate need not be constant over time, and it will not equal the firm's average cost of capital. As a result, simple cost of capital measures, based on rates of return (simple or adjusted) to equity and debt, may be poor explanators of investment spending.
This can be seen in the context of models based on Tobin's q. A good example is the model of Abel and Blanchard (1986), which 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.

The model is based on the standard discounted cash flow rule, "invest in the marginal unit of capital if the present discounted value of the expected flow of profits resulting from the unit is at least equal to the cost of the unit." Let $\pi_t(K_t, I_t)$ be the maximum value of profits at time $t$, given the capital stock $K_t$ and investment level $I_t$, i.e. it is the value of profits assuming that variable factors are used optimally. It depends on $I_t$ because of costs of adjustment; $\partial \pi / \partial I < 0$, and $\partial^2 \pi / \partial I^2 < 0$, i.e. the more rapidly new capital is purchased and installed, the more costly it is. Then the present value of current and future profits is given by:

$$ V_t = E_t \left[ \sum_{j=0}^{\infty} \left( \prod_{i=0}^j (1+R_{t+i+1})^{-1} \right) \pi_{t+j}(K_{t+j}, I_{t+j}) \right] $$

(1)

where $E_t$ denotes an expectation, and $R$ is the discount rate. Maximizing this with respect to $I_t$, subject to the condition $K_t = (1-\delta)K_{t-1} + I_t$ (where $\delta$ is the rate of depreciation), gives the following marginal condition:

$$ -E_t(\partial \pi_t / \partial I_t) = q_t,$$

(2)

where

$$ q_t = E_t \left[ \sum_{j=0}^{\infty} \left( \prod_{i=0}^j (1+R_{t+i+1})^{-1} \right) (\partial \pi_{t+j} / \partial K_{t+j})(1-\delta)^j \right] $$

(3)

In other words investment occurs up to the point where the cost of an additional unit of capital equals the present value of the expected flow of
incremental profits resulting from the unit. Abel and Blanchard estimate both linear and quadratic approximations to \( q_t \), and use vector autoregressive representations of \( R_t \) and \( \partial \pi_t / \partial K_t \) to model expectations of future values. Their representation of \( R_t \) is based on a weighted average of the rates of return on equity and debt.

If the correct discount rates \( R_{t+1} \) were known, eqns. (2) and (3) would indeed accurately represent the optimal investment decision of the firm. The problem is that these discount rates are usually not known, and generally will not equal the average cost of capital of the firm, or some related variable. Instead, these discount rates can only be determined as part of the solution to the firm's optimal investment problem. This involves valuing the firm's options to make (irreversible) marginal investments (now or in the future), and determining the conditions for the optimal exercise of those options. Thus the solution to the investment problem is more complicated than the first-order condition given by (2) and (3) would suggest.

As an example, consider a project that has zero systematic (non-diversifiable) risk. The use of a risk-free interest rate for \( R \) would lead to much too large a value for \( q_t \), and might suggest that an investment expenditure should be made, whereas in fact it should be delayed. Furthermore, there is no simple way to adjust \( R \) properly. The problem is that the calculation ignores the opportunity cost of exercising the option to invest.\(^6\) This may be why Abel and Blanchard conclude that "our data are not sympathetic to the basic restrictions imposed by the \( q \) theory, even extended to allow for simple delivery lags."
4. Does Risk Matter?

Unfortunately, incorporating irreversibility into models of aggregate investment spending is not a simple matter. First, the equations describing optimal investment decisions are extremely nonlinear, even for very simple models. (See my survey paper (1990), and the references in Footnote 2.) Second, it is difficult to measure (and sometimes even identify) the variables or parameters that reflect key components of risk. Partly as a result of this, there has been very limited empirical work to date that tests the importance of irreversibility for the modelling of investment spending. Here, I briefly survey the little empirical work that I am aware of.

One paper that provides a test of irreversibility and its implications is by Bizer and Sichel (1988). They develop a model of capital accumulation and utilization with asymmetric costs of adjustment, i.e., the costs of adjusting the capital stock up or down can differ. If irreversibility is important, one would expect to find that downward adjustment costs exceed upward ones. Bizer and Sichel derive an Euler equation, which they estimate using Hansen and Singleton's (1982) generalized instrumental variable procedure. They do not have firm data, so instead they use 2-digit SIC industry data. They measure asymmetry of adjustment costs with respect to two reference points: a zero level of investment, and a "normal" (average) level of investment.

Their preliminary results indicate some evidence of irreversibility, in particular in primary metals, fabricated metal products, and possibly the paper industry. But they also find that upward adjustment costs exceed downward ones in the food and petroleum industries. This may simply mean that aggregation is masking irreversibility. Other problems include the use
of a single discount factor (the S&P dividend/price ratio, which is very volatile) and cost of capital for all industries. Nonetheless, their approach seems like a promising way to test for effects of irreversibility, particularly if used with disaggregated data. It does not, however, explicitly deal with effects of changes in risk.

In a recent working paper (1986), I performed some very simple non-structural tests for the importance of risk. I used data on the stock market, on the grounds that when product markets become more volatile, we would expect stock prices to also become more volatile, so that the variance of stock returns will be larger. This was indeed the case, for example, during the recessions of 1975 and 1980, and most dramatically during the Great Depression. Thus the variance of aggregate stock returns should be correlated with aggregate product market uncertainty.

Stock returns themselves are also a predictor of aggregate investment spending. My concern was whether the variance of stock returns also has predictive power with respect to investment, and whether that predictive power goes beyond that of stock returns themselves, as well as other variables that would usually appear in an empirical investment equation. I conducted two related exploratory tests. First, I tested and was able to accept the hypothesis that the variance of stock returns Granger-causes the real growth rate of investment. Specifically, the variance of returns is a strong predictor of investment growth, but investment growth does not predict the variance of returns. This is true when total fixed investment is used, and also when structures and equipment are treated separately.

Second, I ran a set of regressions similar to those used by Fischer and Merton (1984) in their study of the predictive power of stock returns. Each investment variable (the growth rates of total fixed investment, investment
in structures, and investment in equipment) is regressed first against lagged values of variance, then against lagged values of variance and lagged values of real stock returns, and finally against lagged variance, lagged stock returns, and the lagged values of four additional variables that often appear in empirical investment equations: the change in the BAA corporate bond rate, the change in the 3-month Treasury bill rate, the change in the rate inflation, and the rate of growth of real GNP.

The results are shown in Table 1. Note that three lagged values of each independent variable appear in the regressions, but the table only shows the sum of the estimated coefficients for each variable, together with an associated t-statistic. In all of the regressions, the quarterly variance of stock returns is computed using CRISP data on daily returns. Specifically, the variance for quarter \( t \) is computed as:

\[ \sigma_t^2 = \frac{1}{n} \sum_{j=1}^{n} x_{t,j}^2 \]  

where \( n \) is the number of days in the quarter, and \( x_{t,j}^2 \) is the logarithmic return from day \( j-1 \) to day \( j \) in quarter \( t \), adjusted for non-trading days by dividing by the square root of the number of days between trades.

Consistent with the causality tests mentioned above, the variance of returns is highly significant when it appears as the only independent variable. Variance continues to be highly significant after adding real stock returns to the regression. This second independent variable is also a significant explanator of the growth of total non-residential investment, as Fischer and Merton found, as well as investment in equipment, but it is not significant for investment in structures. When the remaining explanatory variables are added, variance continues to be significant in the regressions for non-residential investment and structures, but not for
equipment. (The only significant explanator of equipment investment is the BAA bond rate.) This may reflect the fact that the irreversibility of investment is greater for structures than for equipment.

The importance of this risk measure is also evident from the magnitudes of the variance coefficients. As I have shown elsewhere (1984), the quarterly variance of stock returns went from about .01 in the 1960's to about .02 in the mid-1970's. From regressions 3, 6, and 9 we see that this implies an approximately 4.5 percentage point decline in the growth rate of investment in structures (a drop from around 5 percent real growth during the 1960's to only slightly positive real growth), a 2.5 percentage point drop in the growth rate of investment in equipment, and a 3 percentage point drop in the growth rate of total investment.

Of course regressions of this sort are extremely crude, and are based on aggregate data and what is probably a very imperfect measure of risk. (Even if the variance of stock returns is a good proxy for the volatility of cash flows, it does not capture the "peso problem," i.e., changing perceptions of the risk associated with one or more possible future catastrophic events.) Nonetheless, the results suggest that the explicit inclusion of market risk measures may help to improve our ability to explain and predict investment spending, and that the development of structural models that include such measures should be an important research priority.

5. Conclusions.

There are good theoretical reasons to expect market risk to have a major role in the determination of investment spending. This idea is not new; it has been elaborated upon in a number of articles during the past few years. However, it seems to be missing from most empirical work on
investment. This may be a reflection of the fact that most theoretical models of irreversible investment under uncertainty are quite complicated, so that their translation into well-specified empirical models represents a formidable task.

In any case, the gap here between theory and empiricism is somewhat disturbing. While it is clear from the theory that increases in the volatility of, say, interest rates or exchange rates should depress investment, it is not at all clear how large the effect is likely to be. Nor is it clear how important these factors have been as explanators of investment across countries and over time.

Determining the importance of these factors should be a research priority. One approach is to do empirical testing of the sort discussed in the preceding section, perhaps using cross section data for a number of countries. Another approach is to construct simulation models based on theoretical formulations that can be solved either analytically or numerically, and then parameterize them so that they "fit" particular industries. One could then calculate predicted effects of observed changes in, say, price volatility, and compare them to the predicted effects of changes in interest rates or tax rate. Simulation models of this sort could likewise be constructed to predict the effect of a perceived possible shift in the tax regime, the imposition of price controls, etc. Such models may also be a good way to study uncertainty of the "peso problem" sort.
Table 1 - Variance of Stock Returns as a Predictor of Investment  
(Quarterly Data, 1963-4 to 1983-4)

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Variables:  
INGR = Quarterly growth rate of real business fixed investment.  
ISGR = Growth rate of real investment in structures.  
IEGR = Growth rate of real investment in durable equipment.  
VAR = Quarterly variance of real return on NYSE Index.  
RTRN = Real return on NYSE Index.  
DRBAA = Change in BAA corporate bond rate.  
DRTB3 = Change in 3-month Treasury bill rate.  
DINF = Change in inflation rate, as measured by PPI.  
GNPGR = Quarterly growth rate of real GNP.

Note: t-statistics in parentheses.
REFERENCES


FOOTNOTES

1. See Kopcke (1985) for an overview, as well as examples and comparisons of traditional approaches to modelling investment spending.

2. As Akerlof (1970) first demonstrated, when sellers of a good know more about its quality than do buyers, low-quality goods tend to drive high-quality ones from the market. As a result, used goods will sell for less than they would in a world with perfectly informed buyers and sellers.

3. This is developed in the articles by Bernanke (1983) and McDonald and Siegel (1986). Other examples of this literature include Cukierman (1980), Brennan and Schwartz (1985), Majd and Pindyck (1985), Bertola (1989), Pindyck (1988), and Dixit (1989). In the articles by Bernanke and Cukierman, uncertainty over future market conditions is reduced as time passes, so that firms have an incentive to delay investing when markets are volatile. In the other papers, future market conditions are always uncertain. As with a call option on a dividend-paying stock, an investment expenditure should be made only when the value of the resulting project exceeds its cost by a positive amount, and again, increased uncertainty will increase the incentive to delay the investment.

4. Firms obtain their options to invest in various ways. Sometimes they result from patents, or ownership of land or natural resources. More generally, they arise from a firm's managerial resources, technological knowledge, reputation, market position, and possibly scale, all of which may have been built up over time, and which enable the firm to productively undertake investments that individuals or other firms
cannot undertake. Most important, these options to invest are valuable. Indeed, for most firms, a substantial part of their market value is attributable to their options to invest and grow in the future, as opposed to the capital that they already have in place. See Kester (1984) and Pindyck (1988).

5. This point was made by Bernanke (1983), particularly with respect to changes in oil prices. Also, see Evans (1984) and Tatom (1984) for a discussion of the depressive effects of increased interest rate volatility.

6. In principle, one could extend the Abel-Blanchard model to account for irreversibility. For example, one could introduce asymmetric adjustment costs, as Bizer and Sichel (1988) have done. (This is discussed in the next section.) However, in practice it would then be difficult to solve for marginal q and the optimal investment rule.

7. To say that "X causes Y," two conditions should be met. First, X should help to predict Y, i.e. in a regression of Y against past values of Y, the addition of past values of X as independent variables should contribute significantly to the explanatory power of the regression. Second, Y should not help to predict X. (If X helps to predict Y and Y helps to predict X, it is likely that one or more other variables are in fact "causing" both X and Y.)