Real Options, Irreversible Investment and Firm Uncertainty: New Evidence from U.S. Firms

Laarni T. Bulan*†

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Abstract

This paper investigates real options behavior in capital budgeting decisions using a firm-level panel data set of U.S. companies in the manufacturing sector. Specifically, this paper looks are the relationship between the firm's investment to capital ratio and total firm uncertainty, measured as the volatility of the firm's equity returns. Total firm uncertainty is decomposed into its market, industry and firm-specific components. Given that the irreversibility of capital is derived from asset-specificity at the industry level, increased industry uncertainty displays a pronounced negative effect on firm investment consistent with real options behavior. Increased firm-specific uncertainty is also found to depress firm investment - a result that can be attributed to real options behavior and not just managerial risk aversion. The results are robust to various specifications that control for the firm's investment opportunities that are captured by Tobin's q, cash flow, marginal profitability of capital and firm leverage.

*Assistant Professor, Brandeis University International Business School, 415 South Street MS 021, Waltham, MA 02454, USA Phone: 781-736-2294 Fax: 781-736-2269 Email: lbulan@brandeis.edu

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I. INTRODUCTION

What is it about real options that has made it a buzz word on the *Street*? Why is it that real options theory has caught the attention of academics and practitioners alike? In a survey of corporate finance practices in the U.S., Graham and Harvey (2001) find that more than 70 % of the CFOs surveyed rely on discounted cash flows and the Capital Asset Pricing Model (CAPM) for their capital budgeting decisions. Despite the popularity of Net Present Value (NPV), it has long been acknowledged that it fails to capture an important feature of the investment decision - that of managerial flexibility in a dynamic and uncertain environment. Among the various methods that have been devised to address this shortcoming of the NPV model, the use of option-pricing techniques holds the most promise. In contrast to the static NPV invest-now-or-never rule, real option methods maximize the value of the investment opportunity, i.e. maximize the value of a call option.[1]

The ability to delay investment decisions is valuable when the investment is irreversible and the future is uncertain. The irreversibility of investment expenditures stems from capital specificity at the industry level and/or at the firm level.[2] If managers can wait for the resolution

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[1]McDonald and Siegel (1986) present a tractable solution to the valuation of an option to invest in an irreversible project. Similar problems are also investigated in Baldwin (1982), Bernanke (1983) and McDonald and Siegel (1985). Titman (1985) specifically focuses on the valuation of land while Brennan and Schwartz (1985) evaluate investments in natural resource projects.

[2]See McDonald and Siegel (1986), Pindyck (1988) and Dixit and Pindyck (1994). Homogeneous capital goods that are not industry or firm-specific (such as office equipment) are still partially irreversible because of the lemons problem. Abel and Eberly (1994, 1996) and Abel, Dixit, Eberly and Pindyck (1996) define partial irreversibility (or costly reversibility) as the case when the purchase price of capital is greater than its resale price.

of uncertainty before deciding to pursue the irreversible investment, they can avoid potentially large losses by foregoing the investment altogether when the outcome is unfavorable. Hence, a familiar result from option-pricing applies to irreversible investments: the greater the uncertainty in an investment's expected future cash flows, the more valuable is this option to delay the investment. This in turn reduces the incentive for exercising the option today.

This paper investigates real options behavior in capital budgeting decisions of U.S. companies in the manufacturing sector. In particular, this paper tests whether real options models can explain the relationship between firm investment and uncertainty. Although a majority of firms may not actually be employing real options techniques yet, McDonald (2000) points out that arbitrary methods such as hurdle rates and profitability indexes can actually approximate the optimal decision under real options, i.e. the same factors that increase the value of the option to delay investment also increase firm hurdle rates and profitability requirements.

By improving on the empirical methods of prior studies, this paper provides substantial evidence at the firm-level and makes two significant contributions towards finding support for real options behavior of firm managers. First, the approach taken in this paper is to use an "asset-pricing" model to decompose the total uncertainty faced by an individual firm into its systematic and firm-specific components and then relate these measures to the firm's investment behavior. The traditional view asserts that it is only systematic risk (e.g. market uncertainty under the CAPM), as it affects the firm's cost of capital, that should matter for firm investment. Real options models predict the contrary, that it is total risk or total firm uncertainty that should matter for firm investment. By decomposing risk in this manner, we can identify whether firm-specific risk adds value through the firm's investment (or growth) options and hence, identify whether it influences investment decisions. Second, in addition to a market component, total firm uncertainty is decomposed further to account for the effect of industry-wide variations. Distinguishing between industry uncertainty and firm-specific uncertainty is important for irreversible investments. Dixit and Pindyck (1994) argue that the irreversibility of capital is more pronounced at the industry level because capital is industry-specific.[3] In this case, the predictions of real options theory have greater relevance for uncertainty that is industry-wide.

This paper provides empirical support for the prediction of real options models that higher uncertainty reduces incentives for investing. The decomposition of total uncertainty into its market, industry and firm-specific components reveals that periods of higher industry and firm-specific uncertainty are related to lower investment by firms. A one standard deviation increase in industry uncertainty reduces a firm's investment-to-capital ratio by 6.4 %. A one standard deviation increase in firm-specific uncertainty decreases firm investment by 19.3 %. In contrast, a one standard deviation increase in Tobin's q increases investment by only 5 %.[4] The findings point to the importance of industry uncertainty as a determinant of firm investment when capital is industry specific.

In addition, this paper revisits the effect of competition on investment behavior.[5]

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[3]Consider the case where a single firm experiences a negative shock to its profits. Since other firms in the industry are not affected by this shock, the resale value of this firm's capital is high. On the other hand, if the negative shock were industry-wide, then the resale value of its capital would be much lower because all firms in the industry are adversely affected.

[4]These calculations are based on the mean investment-to-capital ratio.

[5]Only two other papers have looked at the effect of competition on investment behavior in a real options framework at the firm or project level: Guiso and Parigi (1999) and Bulan, Mayer and Somerville (2003).

Competition has a differential effect on the investment-uncertainty relationship. This finding provides further evidence for real options behavior and precludes managerial risk aversion as an alternative interpretation of the results.

The remainder of the paper is organized as follows. Section II reviews related empirical studies. Section III presents the empirical model used in the estimation and provides a description of the data. Section IV gives the empirical results and Section V concludes.

II. RELATED LITERATURE

Few papers have attempted to empirically test the investment-uncertainty relationship predicted by irreversible investment models. The evidence has not been completely supportive of the implication that higher uncertainty discourages firm investment. Studies that have been successful in documenting a negative influence of uncertainty on investment have mainly used aggregate data.[6] It is unclear, however, if the same conclusions from real options theory derived at the firm or project level can be made at the macro level or even at the industry level. These papers can only infer real options behavior from the relationship between the level of investment and uncertainty. On the other hand, studies that use project level data have been able to investigate the effect of uncertainty on the timing (as opposed to the level) of investment, which is a direct test of the optimal exercise of real options. These project-level studies however have mixed findings[7]. A third line of inquiry in the empirical literature utilizes firm-level data such as

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[6]See for example Federer (1993), Pindyck & Solimano (1993), Huizinga (1993), Caballero & Pindyck (1996), Holland, Ott & Riddiough (2000), and Ghosal and Loungani (1996, 2000).

[7]See for example, Paddock, Siegel and Smith (1988), Quigg (1993), Favero, Pesaran & Sharma (1994), Hurn and Wright (1994), Moel and Tufano (2002) and Bulan, Mayer and Somerville (2003).

Bell & Campa (1997), Leahy and Whited (1996) and Guiso and Parigi (1999).

Most relevant to this paper is the study by Leahy & Whited (1996). They use a panel of manufacturing firms from Compustat and CRSP to document some stylized facts regarding the relationship between investment and uncertainty over the period 1981-1987. They employ VAR methods to generate volatility forecasts from daily stock returns to measure uncertainty. They control for Tobin's *q* in their main regressions and include the covariance of equity returns with the market return to test the implications of the CAPM for firm investment. Their main finding is that the variance of stock returns has a negative effect on investment that works primarily through Tobin's *q*, i.e. once they control for Tobin's *q*, the variance of equity returns has no predictive power for investment. In addition, they find no evidence that their CAPM-based measure of risk plays a role in the investment decision.

At the firm level the evidence is weak. At the project level, support for real options behavior is more favorable. Nevertheless project level studies remain specific to certain industries (e.g. real estate and mining) and generalizing their findings to other industries may not be straightforward. This paper attempts to provide stronger support for real options models at the firm level by analyzing a heterogenous group of firms from the U.S. manufacturing sector and improving on the empirical methods of previous work.

III. EMPIRICAL SPECIFICATION

A. Measuring Uncertainty

Obtaining a general measure of the uncertainty affecting a firm is not straightforward. Many theoretical models require a measure of the volatility of a firm's demand shocks or more precisely, the volatility of a firm's output price. Other models have also included uncertainty in input costs or supply-side shocks. As an alternative, the measure of uncertainty employed in this paper is the volatility of a firm's stock returns. The advantage of this measure is that it captures the *total* uncertainty that is relevant to the firm in a single variable, facilitating a decomposition of risk into its various components as discussed below. Pindyck (1991) argues that increased volatility in the product markets is translated into increased volatility in the stock market. Leahy and Whited (1996) reason that stock returns capture the changing aspects of a firm's environment that is important to investors. Additionally, Berk, Green and Naik (1999) show that time variation in asset returns are driven by the firm's expectations about its returns from assets in place and from potential growth options. Simply put, common stock represents claims on the future profits of a firm. Innovations to a firm's stock return are reactions to news about the firm's future profitability and future investment opportunities. If markets are efficient, news about asset fundamentals and the firm's future prospects are priced by the market. Hence, the volatility of a firm's stock returns should reflect these variations and provide an adequate measure of the total uncertainty that is relevant for firm-level investment decisions.

Total firm uncertainty for firm *i* in year *t* is measured as the volatility of the firm's equity returns, i.e. the annualized standard deviation of the firm's daily returns in that fiscal year, $\hat{\sigma}_{it}$.[8] Daily returns are used to generate annual volatility measures from non-overlapping samples of return data. This creates an estimation error in $\hat{\sigma}_{it}$ that is uncorrelated over time, which is its advantage over moving-average procedures for calculating volatility that use lower frequency

[8]Volatility is measured over a firm's fiscal year to correspond with reported financial data.

data. In addition, small sample bias is also minimized.[9]

Total uncertainty is decomposed into its aggregate and firm-specific components by estimating the following two-index model. Under the standard i.i.d assumptions for returns in each year,

$$r_{i\tau} = \alpha_{it} + \beta_{it} r_{M\tau} + \gamma_{it} r_{I\tau} + \varepsilon_{i\tau} \ , \qquad (1)$$

where $\mathbf{J}$ = 1, 2, ..., t_i . t_i is the number of trading days in year t, $r_{i\tau}$ is the daily return on firm i's equity, $r_{M\tau}$ is the daily return on the market index, $r_{I\tau}$ is the component of the daily return on firm i's industry index that is orthogonal to the market return, and ε_{it} is a white noise error term with variance $\sigma_{\varepsilon it}$. β_{it} and γ_{it} are the market and industry betas respectively for firm *i* in year *t*, as implied by this two-index model. Using ordinary-least-squares, the estimated betas are $\hat{\beta}_{it}$ and $\hat{\gamma}_{it}$. The resulting standard deviation of residuals from this regression, $\hat{\sigma}_{\varepsilon it}$, is the estimate of firm-specific uncertainty.[10] This measure captures the volatility of returns that is orthogonal to both market and industry movements.

Denote the annual volatility of market returns by $\hat{\sigma}_{Mt}$ and the volatility of industry

[9]Daily returns however are noisy and can capture changes in non-fundamentals. This noise will be factored into measurement error in $\hat{\sigma}_{it}$.

[10]All volatility measures are annualized by multiplying by the square-root of 252 (the number of trading days in a year).

returns for industry I in year t that is orthogonal to the market return by $\hat{\sigma}_{It}$. Using the estimated beta from equation (1), market uncertainty is measured as $\hat{\beta}_{it}\hat{\sigma}_{Mt}$, i.e. the portion of total market uncertainty that matters for the firm. Similarly, industry uncertainty for firm i in industry I is measured as $\hat{\gamma}_{it}\hat{\sigma}_{It}$, i.e. the portion of total industry uncertainty that is relevant to the firm and orthogonal to market movements.

For comparison, an alternative decomposition of uncertainty is estimated where the restriction $\gamma_{it} = 0$ is imposed on equation (1). This scenario is analogous to the Capital Asset Pricing Model (CAPM) and provides a benchmark for comparing the value-added of identifying industry sources of uncertainty. In particular, it allows a test of the hypothesis that the type of uncertainty that impacts valuation when capital is irreversible stems from capital-specificity at the industry level.[11,12]

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[11]It can be argued that alternative asset pricing models will yield different measures of firm-specific uncertainty, such as the Fama-French three-factor model. The choice of risk decomposition in this paper is clearly motivated from a statistical framework and is based on 1) Dixit and Pindyck (1994) and 2) the straightforward economic interpretation of the results from a real investment perspective. As a robustness check, the Fama-French three-factor model is used and similar results are found in terms of the relationship between firm investment and firm-specific uncertainty. The difficulty arises in the interpretation of the results for the three "systematic" factor risks and their role in firm investment behavior.

[12]It is possible that the individual risk components of stock return volatility may not correspond to the true systematic and unsystematic risks that the firm faces due to the fact that stock return volatility is dependent on the degree of "moneyness" of a firm's real options. To address this issue, measures of total uncertainty, market uncertainty and industry uncertainty are constructed similar to Leahy and Whited (1996). (Instead of a risk

An important issue in the measurement of uncertainty is that the measure has to be forward-looking since it should reflect future profitability. The volatility measures calculated above are ex-post estimates. Under a rational expectations assumption, we can use realized values of volatility to proxy for expected volatility. This adds a rational expectations error to the error term that is orthogonal to information available at the beginning of each time period. Schwert (1989) reports strong persistence in stock return volatility where lagged volatility is the most important variable in predicting next period's stock return volatility. Thus, lagged values of volatility can be used as valid instruments in the estimation.

The effect of financial leverage on stock return volatility was first pointed out by Black (1976). A firm becomes more highly levered when the value of its equity drops. This makes the firm's equity riskier and raises the volatility of its stock returns. Additionally, leverage can have the same effect on the firm's equity beta. Hence there is the concern that uncertainty is only measuring a firm's indebtedness since it has been shown that leverage negatively affects firm investment. To address this leverage effect, the betas and volatility measures are multiplied by the ratio of it's equity to total firm value, as derived in Christie (1982), to calculate measures of uncertainty that are free of leverage effects.[13]

B. Investment Equation

The goal of this paper is to identify the role of uncertainty as it affects investment behavior at the firm level. Pindyck (1988) presents the firm's problem as a decision to invest in

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decomposition, Leahy and Whited include total stock return volatility and the covariance of a firm's stock return with the market return.) With these alternative measures of uncertainty, the findings in section IV are unchanged.

[13]The shortcoming of this scaling is that it assumes debt is riskless. The median debt-to-equity ratio in the sample is 0.28.

the marginal unit of capital which is valued as a real option. The firm's objective is to choose its optimal capital stock that maximizes firm value. To do this, the firm evaluates a succession of options to invest in each additional unit of capital. The firm exercises each investment option consecutively until it reaches its optimal capital stock. When uncertainty is greater, the value of the option to invest in the additional unit of capital increases. Firm value is maximized when the option to invest in the marginal unit is kept alive. This will correspond to a lower optimal capital stock. Consequently, higher uncertainty discourages firm investment.[14] Hence, we expect a negative relationship between firm investment and firm uncertainty.

In the estimation, it is important to sufficiently control for investment opportunities. Q theory relates the rate of investment (investment to capital ratio) of a firm to it's marginal *q*, the present value of all future marginal returns to capital. Theoretically, the effect of uncertainty on firm investment will be captured by marginal *q*. In practice, we can only observe average *q* (or Tobin's *q*), which is measured using the firm's average returns to capital.[15] It has been well documented in the literature that Tobin's *q* exhibits low explanatory power in investment regressions.[16] Thus, other variables that forecast investment opportunities and help predict marginal *q* will also contribute to explaining investment behavior. Such variables that are

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[14]See McDonald and Siegel (1986) or Dixit and Pindyck (1994) for the discrete project framework.

[15]Hayashi (1982) shows the conditions under which marginal *q* and average *q* are equivalent: perfect competition and linearly homogenous production and installation functions.

[16]Recent studies revisiting q-theory and investment regressions have sought to explain this empirical anomaly as either (1) measurement error in Tobin's q or (2) non-linearity of the investment function. See for example Erickson and Whited (2000), Bond and Cummins (2001), Gomes (2001), Cooper and Ejarque (2001) and Abel and Eberly (2002).

prevalent in the literature are firm output (measured by total sales) and cash flow[17]. (See appendix table A1.)

To control for investment opportunities, I include Tobin's *q*, a sales-based measure of the firm's marginal profitability of capital[18] (MPK) and cash flow (scaled by the firm's capital stock) in the basic empirical specification. The appendix explains in detail the derivation of these variables. The empirical model to be estimated is:

$$\left(\frac{I}{K}\right)_{it} = \alpha_0 + \alpha_1 Q_{it-1} + \alpha_2 \left(\frac{CF}{K}\right)_{it-1} + \alpha_3 MPK_{it-1} + \alpha_4 \hat{\beta}_{it}\hat{\sigma}_{Mt} + \alpha_5 \hat{\gamma}_{it}\hat{\sigma}_{It} + \alpha_6 \hat{\sigma}_{\varepsilon it} + \xi_{it} + \nu_i + \eta_t \qquad (2)$$

The dependent variable is firm investment (I) scaled by the beginning-of-period capital stock (K). The investment decision is assumed to be made at the beginning of year *t*. Tobin's *q* (Q),

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[17]To examine the effects of financing constraints due to capital market imperfections, Fazzari, Hubbard & Petersen (1988) estimate a modified *q*-theory regression of investment on Tobin's *q* and cash flow, where they use cash flow as a measure of internal funds. Based on the premise that Tobin's *q* sufficiently controls for the investment opportunities of the firm, a significant positive coefficient on cash flow is evidence in favor of a financing constraints story. Contrary to most prior work however, the results in the next section display no differential impact of cash flow on investment for firms that are more financially constrained. One possible explanation is that cash flow is highly correlated with profitability.

[18]Tobin's q is a market-to-book measure of the firm's total assets and MPK is a sales-based measure of profitability proposed by Gilchrist and Himmelberg (1998). MPK=**2**(Sales/K) where **2** is an industry level constant. See the appendix for an explanation of this calculation.

MPK, and cash flow (CF) are measured as end of year values for *t-1,* and hence are all predetermined regressors. Since there is strong persistence in these measures, they serve as controls for the firm's investment opportunities for the coming year. The uncertainty measures represent rational expectations of the variability in the firm's profits over year *t.* ν_i *and* η_t are a firm fixed effect and a time fixed effect, respectively. The presence of firm fixed effects can be attributed to characteristics of the investment policy that are time invariant and specific to each firm. Additionally, sample selection and errors-in-variables could also introduce this same type of bias in the error term. The time fixed effect is added to control for time variation caused by aggregate shocks. Implicit in this empirical specification is the assumption that invested capital becomes productive within the year.[19]

In this reduced-form investment regression, finding a role for uncertainty that is not captured by Tobin's *q*, MPK and cash flow would provide some insight into the channels by which the market, industry and firm-specific components of uncertainty affect firm investment behavior. The use of Tobin's *q* in place of marginal *q* assumes perfect competition and linear homogeneity in investment (I) and capital (K) of the production and installation functions. It is highly unlikely that firms are perfectly competitive. In addition, and more importantly, the irreversibility of capital is inconsistent with a production technology and adjustment cost function that are linearly homogeneous in I and K. Irreversibility matters when investment

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[19]Gilchrist and Himmelberg (1998) report that time to build is on average about 6 months for manufacturing firms. Time to build (or investment lags) has been incorporated into the irreversible investment framework by Majd and Pindyck (1987) and Bar-Ilan and Strange (1996). Their common finding is that short periods of time to build still preserves the negative impact of uncertainty on investment.

decisions today affect investment decisions tomorrow. With linear homogeneity, the investment decision rule is independent of the current level of the capital stock, which means there is no inter-temporal link between today's and tomorrow's investment decisions. Thus, there is good reason to believe that uncertainty will contain additional information for investment that affects firm hurdle rates and option values because of the irreversibility effects that are not captured by Tobin's *q*, *MPK* or cash flow.

C. Data

Following previous empirical work in the investment-Q literature, the data set is a firm-level panel of all U.S. manufacturing firms from the annual 2000 Compustat files. Firms with missing years are deleted as well as firm-year observations with missing or inconsistent data. To account for mergers or large acquisitions, observations with a greater than 20 % change in the book value of assets are dropped. Daily stock return data is taken from the 2000 CRSP files where returns are adjusted for stock splits and dividends and the number of days between trades. Only those observations with less than 5 days between trades are included to eliminate illiquid stocks. Firm-years with less than 125 return observations are then deleted, restricting the sample to firms that traded for at least 50% of the trading days in a year. The value weighted NYSE index is used as the market return series and a value-weighted industry index for each 3-digit manufacturing SIC group (SIC codes 200-399) is constructed.

The working data set comes from merging the Compustat and CRSP firms that have at least 3 annual observations. The result is a sample of 2,901 firms from 1964-1999 consisting of 29,639 firm-year observations. Outlier rules are imposed on the firm variables by setting the values at the upper and lower tails equal to the 99^{th} and 1^{st} percentiles respectively. It is assumed that all the Compustat variables used in this analysis are end-of-year values except for investment, which is assumed to be made at the beginning of the year. The appendix specifies in greater detail the variables used in the estimation. Descriptive statistics and correlations are given in Tables 1a-1b. Note that compared to the control variables, the correlation of investment with the various uncertainty measures are close to zero and except for industry uncertainty, are all positive in sign. Contrary to the expected negative relationship between investment and uncertainty, this points to the need to properly control for exogenous factors that affect investment that are also correlated with uncertainty.

D. Estimation Methodology

Estimation of equation (2) is by instrumental variables (Two Stage Least Squares) with a robust variance-covariance estimator. Since realized values of volatility are used to proxy for expected uncertainty, the instrumental variables methodology addresses the issue of endogeneity in these uncertainty measures. In addition, errors-in-variables resulting from the use of stock return volatility to measure firm uncertainty is also accounted for by this estimation procedure. Standard errors are computed to allow for correlation within firms across time. The instruments are the predetermined right-hand side variables from equation (2), lagged values of all uncertainty measures, plus lagged values of the ratio of investment to capital, the ratio of sales to capital and year dummies. The use of lagged observations as instruments reduces the sample to 2,722 firms consisting of 19,579 firm-year observations.

A forward mean-differencing procedure (Helmert procedure)[20] is implemented to remove firm fixed effects. This is a weighted transformation that subtracts the mean of all the future observations of each variable. Hence, estimation of equation (2) is similar to the fixed-

[20]See Arellano & Bover (1995) for a detailed explanation of this methodology.

effects methodology. The advantage of the Helmert procedure over first-differencing or mean-differencing is that it preserves all lagged values of the explanatory variables as valid instruments. All current and lagged values of the right-hand side variables remain uncorrelated with the transformed error term. This procedure also preserves homoskedasticity (if the original error term is homoskedastic) and does not induce serial correlation. To control for time-fixed effects, year dummies are included in the regression. As a result, identification will come from cross-sectional differences in the data.

IV. EMPIRICAL RESULTS

In the tables that follow, the regressions are based on equation (2). Model (a) uses the single measure of total return volatility as a proxy for total firm uncertainty, model (b) decomposes total firm uncertainty into its market and firm-specific components, while model (c) decomposes total firm uncertainty into its market, industry and firm-specific components. The base specification includes all the control variables: Tobin's *q*, *MPK* and cash flow. It should be noted that in these reduced form regressions, we can only make statements about the short run effect of uncertainty on investment. Further analysis will require a richer structural framework relating investment to uncertainty.

The main findings support a strong negative influence of uncertainty on investment that is not captured by Tobin’s *q*, *MPK* or cash flow, contrary to the results of Leahy and Whited (1996). Greater industry and firm-specific uncertainty significantly reduce investment in a manner consistent with real options behavior.

A. Base Regressions

Table 2 presents the results of the base regressions. The first three columns report the investment regressions without the control variables. It is striking that both total uncertainty and firm-specific uncertainty have a highly significant negative effect on investment.[21] The coefficient on industry uncertainty is negative but not significantly different from zero. Surprisingly, the coefficient on market uncertainty is positive and significant. Under the null hypothesis, market uncertainty should affect investment negatively through the discount rate. With the addition of the control variables in the last three columns, the coefficient on market uncertainty becomes insignificant and is very close to zero. The coefficients on Tobin's *q*, MPK and cash flow are all of the expected signs and significant at the 5 % level. Clearly, without the control variables market uncertainty proxies for investment opportunities, i.e. a higher market beta predicts increased profitability via higher expected returns on the firm's equity. In equilibrium, the marginal cost of capital equals its marginal profitability. In a reduced-form regression, this implies that market uncertainty can have two opposing effects on investment. In fact, in most of the regressions that follow, the coefficient on market uncertainty is not statistically different from zero. With the inclusion of the controls for investment opportunities, the coefficients on industry and firm-specific uncertainty are negative and significant at the 5 % level or better. Based on the last column in table 2, a one standard deviation increase in industry uncertainty reduces a firm's investment-to-capital ratio from its mean by 6.4 % while a one standard deviation increase in firm-specific uncertainty decreases firm investment by 19.3 %. In contrast, a one standard deviation increase in Tobin's q increases investment by only 5 %. Clearly, industry sources of variation are important determinants of investment decisions. If

[21]Since cross-sectional CAPM regressions normally have low R-squares, most of the variation in total returns is due to the variation in the residuals. Hence, we observe similar results with the coefficients on total uncertainty and firm-specific uncertainty.

most capital expenditures are irreversible due to capital being industry-specific, then this result is consistent with real options models. The option to delay investment is more valuable when capital is irreversible.[22]

An alternative interpretation of these results independent of real options behavior is simple risk aversion of managers. If a substantial fraction of the manager's wealth is in the company's equity, then he or she is exposed to the firm's idiosyncratic risk. A risk-averse manager will require a higher rate of return on the firm's investments than what is dictated by the capital markets. This can cause the manager to forego profitable investment projects that would increase the riskiness of the firm. Under this scenario greater firm-specific risk would lower firm investment.[23] In the next sub-section, a variety of sample splits is performed to verify whether the negative relationship between investment and uncertainty is indeed due to real options behavior.

From *q* theory we know that the firm's investment decision today depends on its expected marginal profitability of capital in this period and in all future periods. Given the strong persistence in MPK, we can use current MPK as a first order approximation of the future profitability of the firm. Table 3 shows how well the explanatory variables in the base regressions can predict next period's MPK. The dependent variable here is realized MPK and the uncertainty variables are measured over the same year as MPK.

The coefficient on market uncertainty is positive and highly significant, even after controlling for lagged MPK. This points to the predictive power of systematic risk for the firm's

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[22]Even with the inclusion of a lagged (I/K) term, the results between investment and uncertainty remain unchanged.

[23]See, for example, Himmelberg, Hubbard and Love (2001).

investment opportunities as mentioned above.[24] Industry uncertainty is not significantly related to MPK. On the other hand, firm-specific uncertainty is negatively correlated with MPK. If we regard MPK as the "return" on the firm's investment, these results are consistent with real options models as well. In a q-theory framework, marginal q is equal to the expected present value of the firm's current and future MPK. Under the assumption of complete irreversibility of capital, Abel, Dixit, Eberly and Pindyck (1996) show that marginal q can be decomposed into the marginal value of a firm's existing capital stock *minus* the marginal value of a firm's call options to increase the capital stock. In this model, since marginal q is a sufficient statistic for investment, the option effects of uncertainty on investment are fully capitalized in the firm's current and future MPK. Greater uncertainty will make the call options to invest more valuable reducing marginal q. The results in Table 3 suggest that periods of high firm-specific uncertainty are associated with smaller returns to capital which in turn induces less investment while periods of low firm-specific uncertainty are associated with greater returns to capital that encourage investment.

B. Sample Splits

In this section, sample splits are implemented to examine the robustness of the negative investment-uncertainty relationship to differences in the irreversibility of capital, industry competition and firm size. Sub-samples of the data are created by dividing the full sample at the median average-firm value of the conditioning variable except where noted. These regressions

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[24] Shin and Stulz (2000) also find a positive correlation between systematic equity risk (measured as the systematic component of the variance of equity returns) and Tobin's *q*.

are reported in Tables 4-6.[25]

Up to this point, this paper has only referred to the firm's investment options as call options to increase its capital stock. Nonetheless firms may be able to decrease their stock of capital, albeit in a costly manner. Abel, Dixit, Eberly and Pindyck (1996) consider the more general scenario where they assume the partial irreversibility (or equivalently, costly reversibility) of capital. In this case, a firm has call options to invest as well as put options to disinvest. When a firm invests in an additional unit of capital, it extinguishes the call option to invest in that unit of capital in the future - which is a cost of investing. At the same time, investment in that same unit of capital gives the firm a put option to sell that unit of capital in the future - which is a benefit from investing. The effect of higher uncertainty on the incentives to invest is thus indeterminate and will depend on the interaction between the firm's call and put options.

To address this ambiguity, a firm's capital expenditures are classified according to their degree of irreversibility. The details of this classification scheme are shown in Appendix B.[26] For each two-digit SIC industry, total investment is broken down into the type of equipment or structure. Using this grouping, each investment type is classified as reversible or irreversible based on industry-specificity. An irreversibility index is constructed according to the percentage of industry-specific capital expenditures in a two-digit SIC industry. The greater share of

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[25]Splits conducted at the top and bottom third of the sample yield similar, and mostly more significant results. Other variations of sample splits at quartiles and cross-quartiles (competition and size, etc.) have also been tested and the findings are similar to those reported here.

[26]This classification is derived from the Fixed Reproducible Tangible Wealth Data produced by the Bureau of Economic Analysis.

industry-specific investments made by firms in an industry, the more "irreversible" that industry is. The sample is divided at the median irreversibility index.[27] If a firm's capital expenditures are predominantly irreversible, then their call options for expansion are more valuable than their put options for contraction. Furthermore, we should expect this to be the case at the industry level because of irreversibility derived from the industry-specificity of capital. Hence, the negative effect of *industry uncertainty* on the incentives to invest and increase the capital stock should be more dominant for irreversible firms compared to reversible firms.

The results of this sample split are given in Table 4. Industry uncertainty has a negative coefficient significant at the 10 % level for irreversible firms while the coefficient is insignificant for reversible firms. These findings are consistent with real options behavior when capital is industry-specific. The coefficients on firm-specific uncertainty in these regressions, however, are quite puzzling. For irreversible firms, firm-specific uncertainty has no effect on investment, but for reversible firms, the coefficients on firm-specific uncertainty are negative and significant at the 1 % level. This is opposite of what we would expect if we believe asset-specificity at the firm level should also be contributing to the irreversibility of capital.[28]

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[27]Since industries can only be classified at the two digit level, the "median" index value does not correspond to an exact 50/50 division of the sample. Guiso and Parigi (1999) perform a similar exercise where they measure the irreversibility of firms according to (1) the probability that a firm's capital can be sold in the secondary markets (estimated from survey data) and (2) the correlation of a firm's output with its industry group, i.e. low correlation implies low irreversibility.

[28]It is possible that this classification scheme at the 2-digit SIC level could also be capturing a size effect. The reversible sub-sample contains larger firms compared to the irreversible sub-sample. See Table 6 for the size regressions. Ideally, we would want to be able to classify irreversibility at the firm level and not just at the aggregate 2-digit SIC level.

Next, the effect of competition on the investment-uncertainty relationship is examined.[29] The full sample is split according to high and low degrees of competition based on industry concentration ratios from the 1992 Census of Manufactures. The concentration ratios measure the share of individual activity accounted for by the four largest companies in each four-digit industry. A lower concentration ratio implies a more competitive industry. The median industry concentration ratio is 35 %. These competition regressions are reported in Table 5.[30]

The coefficients on both industry uncertainty and firm-specific uncertainty for less competitive firms are negative and significant at the 5 % level or better while for more competitive firms they are still negative but insignificant. It is apparent that competition reduces the negative impact of uncertainty on investment. Guiso and Parigi (1999) and Bulan, Mayer and Somerville (2003) have similar findings.[31] These results are consistent with models that predict the fear of preemption could lead a firm to exercise early despite high levels of uncertainty.

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[29]Trigeorgis (1996) and Grenadier (2002) show that competition mitigates the option effect of uncertainty on investment. On the other hand, Novy-Marx (2003) argues that the real option premium is still significant in a strategic equilibrium. According to Kulatilaka and Perotti (1998), the nature of competition determines whether the real option premium is affected or not.

[30]In this exercise, missing industries from the Census of Manufactures reduced the sample to 1634 firms.

[31]Guiso and Parigi use the firm's profit margin as a proxy for market power while Bulan, Mayer and Somerville measure competition by the actual number of competitors that a firm has. Both studies find that competition reduces the negative effect of uncertainty on investment at the firm-level and project level respectively. Ghosal and Loungani (1996) find the opposite effect using industry level data, i.e. the negative relationship between investment and uncertainty is more prominent in more competitive industries (where competition is measured by the degree of seller concentration).

Previous studies that have found a negative relationship between investment and firm uncertainty have not adequately been able to rule out the alternative explanation where managers are risk-averse and care about their firm's idiosyncratic risk. Certain types of compensation contracts can cause risk-averse managers to pass up risky positive NPV projects (see for example Smith and Stulz (1985)) resulting in the negative relationship between investment and uncertainty that we see in the data. If it can be shown that the nature of industry competition is not systematically related to a manager's compensation, and consequently to his risk-taking behavior, then the results in Table 5 rule out this alternative story. This is indeed the case. Using data from Chakraborty, Shiekh and Subramanian (2004), I find no significant relationship between CEO incentives and industry competition measures.[32] In addition, the inclusion of firm fixed effects in the estimation of equation (2) further controls for the variation in executive compensation contracts across firms. Since competition has a differential effect on the investment-uncertainty relationship that is unrelated to managerial risk aversion, we can attribute the findings of this paper to real options behavior.

Firm size has repeatedly been shown to affect investment regressions. In Table 6 the sample is split according to firm size as measured by the firm's total assets scaled by the CPI (1992=100). Each firm's average size is calculated over time, then the full sample is divided at the median average firm size. Industry uncertainty has a significant negative effect on investment for large firms that is absent for small firms. The coefficients on firm-specific uncertainty are

[32]CEO incentives are calculated in two ways according to Jensen and Murphy (1990) and Core and Guay (2001): 1) the sensitivity of an executive's portfolio of stock and options to a change in firm value and 2) total pay (including options) sensitivity to a change in firm value. I am grateful to Atreya Chakraborty, Shahbaz Shiekh and Narayanan Subramanian for providing their incentives data, derived from Execucomp 2003.

negative and significant at the 1 % level for both large and small firms. Although it seems that this effect is stronger for large firms, we cannot reject the hypothesis that the coefficients are different across sub-samples at the 10 % level. Firm size is a reasonable proxy for market power, i.e. larger firms have greater market power and will behave more like monopolists while smaller firms with less market power will exhibit more competitive behavior. This is precisely the competition scenario discussed above and indeed the findings here are similar to Table 5. In fact, it can be argued that competition should matter more for industry uncertainty than firm-specific uncertainty since a firm can still realize the option value of waiting and act more like a monopolist when it observes firm-specific shocks to its profitability.

Another plausible explanation for this size effect is that larger firms are usually associated with having more capital intensive technologies to achieve greater economies of scale. Capital intensive technologies could be a proxy for the degree of substitutability of labor for capital. The inability to substitute labor for capital affects the irreversibility of invested capital in that the firm cannot vary its production inputs in response to negative demand shocks. In this sense, large firms are more "irreversible" than small firms. Hence, the larger, more "irreversible" firms will exhibit a more negative coefficient on uncertainty compared to small firms. In fact, in the models of Hartman (1972) and Abel (1983) it is precisely the ability to substitute labor for capital that makes a firm more "reversible," which in turn mitigates the negative effect of uncertainty on investment.[33]

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[33]Contrary to these results, Ghosal and Loungani (2000) find that the negative relationship between investment and uncertainty at the industry level is more significant in industries consisting mostly of smaller firms and they attribute their findings to small firms being financially constrained. However, it can be argued that unconstrained firms are better able to take advantage of the option value of waiting to invest when uncertainty is

Overall, the common finding in these sub-sample regressions is that industry uncertainty has a statistically significant effect on investment that is consistent with irreversibility and competition at the industry level. 1) The greater the degree of industry-specificity of capital (and hence the more irreversible the firm's investments are), the more valuable is the option to delay investment when industry uncertainty is higher. 2) When firms observe the same industry shocks to their profitability, preemption by competitors can induce early investment and mitigate the negative effect of industry uncertainty on firm investment.

C. Leverage

In a Modigliani-Miller (MM) world, the firm's capital structure choice is irrelevant for investment decisions. Most papers in the real options literature have implicitly assumed a MM framework by ignoring the issue of financing.[34] Myers (1977) has argued that the conflict of interest between equity-holders and debt-holders prevents firms from pursuing positive NPV projects in the presence of risky debt. As shown in Table A1 in the appendix, a firm's leverage ratio has a significant negative effect on investment. As previously discussed, there is the concern that the volatility of a firm's stock returns is simply a measure of a firm's indebtedness. To address this issue, Table 7 presents regressions which include the firm's leverage ratio (debt to total firm value) with both levered and unlevered volatility measures. Unlevered volatility is calculated as the firm's levered volatility multiplied by the ratio of its equity to the sum of debt and equity.[35] The firm's beta is also adjusted in the same manner to obtain an unlevered beta. In

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high.

[34]A few exceptions are Mauer and Triantis (1994) and Mauer and Ott (2000).

[35]See Christie(1982) for a derivation of this adjustment factor.

addition, the base regressions are estimated on a sub-sample of low leverage firms corresponding to the bottom third of firms in the sample.[36] This sub-sample of low leverage firms has a mean leverage ratio of 4.3 %. The results are all similar to that of the base regressions in Table 2. Industry and firm-specific uncertainty still have significant negative coefficients either as levered or unlevered measures. Clearly, debt matters for investment. In addition, the results of the previous section on irreversibility, competition, and firm size still hold with this leverage adjustment.[37] Incorporating the effects of financing decisions into a real options framework is still a relatively new area of research. A firm's investment and financing decisions are not mutually exclusive decisions. Better solutions to address leverage concerns are a consideration for future work.

V. CONCLUSIONS & EXTENSIONS

This paper finds substantial evidence in favor of real options models not previously documented at the firm level. The main finding is that greater uncertainty in a firm's environment significantly reduces investment and that effect is present even after controlling for

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[36]The 33rd percentile has a 12 % leverage ratio.

[37]It should be noted that this adjustment factor used to scale volatility is based on the assumption of riskless debt. Furthermore, Schwert (1989) also reports that leverage explains a relatively small portion of the movements in stock return volatility. Hence it is not clear whether this specification with unlevered measures of volatility is preferable. Another difficulty in drawing more concrete inferences from this exercise is the potential endogeneity in the choice of debt. The firm's level of corporate debt could be a function of its own riskiness. Furthermore, debt has also been shown to negatively forecast MPK. Lang, Ofek and Stulz (1996) have found evidence that a firm's leverage is negatively related to the future growth of a firm.

investment opportunities captured by Tobin's *q, MPK* and cash flow. Greater firm-specific uncertainty is found to depress firm investment because of the option to delay. In addition, firms reduce their investments when industry uncertainty is high and their investments are irreversible due to capital specificity at the industry level. Increased competition is also found to diminish the value of the option to delay investment during periods of higher industry uncertainty.

An extension of this paper would be to derive an empirically testable relationship between investment and uncertainty from a structural model of investment where profits are a function of market, industry and firm-specific shocks. Differentiating between these types of shocks should allow one to model directly the impact of industry uncertainty on the irreversibility of new investments because of capital specificity. Furthermore, a structural model will be able to distinguish between the uncertainty that affects investment through the cost of capital and the uncertainty that affects the option to delay investment. This would clarify the role of systematic risk as it affects investment through the cost of capital and through investment opportunities.

Analyzing the role of financial factors in a real options model of investment is another area of research that is open to new contributions. A formal model that can incorporate financing constraints into the irreversible investment framework is desirable. Most of the existing real options models have not taken into account the role of financing constraints, whereas the investment literature has widely investigated this issue in empirical studies and has provided significant evidence in favor of the effect of financial factors on the investment decisions of firms.

APPENDIX A

A. Firm Variables

The following are the firm variables used in the empirical estimation taken from the COMPUSTAT 2000 full coverage, industrial and research files. All values are measured in nominal terms except where noted. All time t variables are end of fiscal year values. Cash flow, investment and sales are all scaled by the beginning of period capital stock (lagged K).

Assets (A): Reported total Assets

Book to Market Ratio (B/E): B is the book value of the firm's equity, calculated as total assets minus total liabilities and E is the market value of common equity plus the liquidating value of preferred equity

Cash Flow (CF): income before extraordinary items plus depreciation and amortization where

$$\left(\frac{CF}{K}\right)_t = \frac{CF_t}{K_{t-1}}$$

Debt-Equity ratio (D/E): D is the book value of long term debt plus current liabilities and E is the market value of common equity plus the liquidating value of preferred equity

Investment (I): capital expenditures on property, plant and equipment excluding acquisitions

Investment to Capital ratio: $\left(\frac{I}{K}\right)_t = \frac{I_t}{K_{t-1}}$

Marginal Product of Capital: $MPK_t = \frac{\theta S_t}{K_{t-1}}$

where S is firm sales and θ is an industry level constant measured as $\theta = \left(1 + \eta^{-1}\right)\alpha_k$. Assuming a Cobb Douglas production function with a single variable input, η is the firm's price elasticity of demand and α_k is the capital share of output. Ignoring adjustment costs, MPK should be equal to the cost of capital, where the cost of capital is measured as the risk-adjusted discount rate, r_{it} plus the rate of depreciation of capital, δ_{it}. I.e.,

$$\theta_j = \left(\frac{1}{N_j}\sum_{i\in I(j)}\sum_{t\in T(i)}\left(S/K\right)_{it}\right)^{-1}\frac{1}{N_j}\sum_{i\in I(j)}\sum_{t\in T(i)}\left(r_{it}+\delta_{it}\right),$$

where N_j is the number of firm-year observations in industry j. The average cost of capital is set equal to 0.18 . See Gilchrist and Himmelberg (1998) for further details.

Replacement value of the capital stock: $K_t = \left[K_{t-1}\left(\frac{P_t}{P_{t-1}}\right) + I_t \right]\left(1 - \frac{2}{L}\right)$

where P_t is the price deflator for non-residential fixed investment from NIPA (National Income and Product Accounts and L is the average of L_t, the useful life of capital goods which is calculated as:

$$L_t = \frac{GK_{t-1} + I_t}{DEPR_t}$$

where GK is reported gross property, plant and equipment and DEPR is capital depreciation. See Salinger and Summers (1983) for a detailed explanation of this perpetual inventory method.

Tobin's q : $q_t = \frac{E_t + TL_t}{A_t}$

where E is the market value of common equity plus the liquidating value of preferred equity, TL is the book value of total liabilities, and A is the firm's reported total assets as measured in Gilchrist and Himmelberg (1998).

B. Volatility Variables

Total volatility: $\hat{\sigma}_{it} = \sqrt{\frac{1}{t_i}\sum_{\tau=1}^{t_i}(r_{i\tau} - \bar{r}_{it})^2}$

Market Volatility: $\hat{\sigma}_{Mt} = \sqrt{\frac{1}{t_i}\sum_{\tau=1}^{t_i}(r_{M\tau} - \bar{r}_{Mt})^2}$

Industry Volatility: $\hat{\sigma}_{It} = \sqrt{\frac{1}{t_i}\sum_{\tau=1}^{t_i}(r_{I\tau} - \bar{r}_{It})^2}$

Firm-Specific Volatility: $\hat{\sigma}_{\varepsilon it} = \sqrt{\frac{1}{t_i}\sum_{\tau=1}^{t_i}\hat{\varepsilon}_{i\tau}^2}$,

where **J** = 1, 2, ..., t_i . t_i is the number of trading days in year t, r_{iJ} is the daily return on firm i's equity, r_{MJ} is the daily market index return, r_{IJ} is the daily industry index return of firm i's three-digit SIC group that is orthogonal to the market return, g_{iJ} is the residual from equation (1). All volatility estimates are annualized.

Table A1: Standard Investment Regressions

Panel A:

Variable	(1)	(2)	(3)	(4)	(5)
Tobin's q	0.0389	0.0204	0.0256	0.0170	0.0109
	(6.04)	(3.43)	(3.79)	(2.82)	(1.85)
MPK_{t-1}		1.0328		0.8781	0.8752
		(11.78)		(8.62)	(8.67)
$(CF/K)_{t-1}$			0.0668	0.0305	0.0267
			(7.20)	(2.96)	(2.55)
D/(D+E)					-0.0960
					-(5.30)
F(n,2722)	16.52	23.17	18.64	23.49	25.05
p-value	0	0	0	0	0
Root MSE	0.11884	0.11485	0.1153	0.11285	0.11223
No. of Firms	2722	2722	2722	2722	2722
No. of observations	19579	19579	19579	19579	19579

Panel B:

Variable	(1)	(2)	(3)	(4)	(5)
$(I/K)_{t-1}$	0.2381	0.1700	0.2247	0.2193	0.2132
	(14.00)	(6.65)	(13.17)	(8.72)	(8.48)
Tobin's q	0.0318	0.0252	0.0208	0.0205	0.0154
	(5.57)	(4.67)	(3.55)	(3.61)	(2.82)
MPK_{t-1}		0.4812		0.0403	0.0541
		(4.16)		(0.31)	(0.41)
$(CF/K)_{t-1}$			0.0569	0.0555	0.0524
			(6.59)	(5.44)	(5.04)
$D/(D+E)_{t-1}$					-0.0647
					-(4.31)
F(n,2721)	26.33	28.66	26.33	28.88	29.47
p-value	0	0	0	0	0
Root MSE	0.11308	0.10999	0.11047	0.11012	0.10957
No. of Firms	2722	2722	2722	2722	2722
No. of observations	19579	19579	19579	19579	19579

1) The dependent variable is I/K.
2) Estimation is by instrumental variables (2SLS). Instruments are the lagged values of all the right-hand side variables plus lagged Sales/K, lagged I/K, and year dummies.
3) Robust standard errors are calculated that allow for correlation within firms. T-statistics are in parenthesis.
4) n=33+number of regressors.

APPENDIX B

Table B1: Irreversibility Classification of Equipment or Structure Investments

Irreversible (Industry Specific)	**Reversible (Non-Industry Specific)**
Metalworking machinery	Autos
Special industry machinery	Communication equipment
Agricultural machinery, except tractors	Computer printers
Commercial warehouses	Computer storage devices
Construction machinery, except tractors	Computer tape drives
Construction tractors	Computer terminals
Electrical transmission, distribution,	Direct access storage devices
and industrial apparatus	General industrial, including materials handling, equipment
Farm related buildings and structures	Household appliances
Farm tractors	Household furniture
Industrial buildings	Internal combustion engines
Other nonfarm structures	Mainframe computers
Other nonresidential equipment	Mobile structures
Aircraft	Other furniture
Instruments	Other office equipment
Office buildings	Personal computers
Other electrical equipment	Photocopy and related equipment
Other fabricated metal products	Steam engines
Service industry machinery	Trucks, buses, and truck trailers

1) The Fixed Reproducible Tangible Wealth Data produced by the Bureau of Economic Analysis reports capital expenditures of each two digit SIC industry according to the above criteria. Industries are then classified as Irreversible or Reversible based on the industry-specificity of these investments.

Table B2: Two Digit SIC Industry Irreversibility Ranking

SIC	Industries	Fraction of Irreversible Investments	*Index*
20	Food and kindred products	0.568	7
21	Tobacco products	0.521	3
22	Textile mill products	0.811	19
23	Apparel and other textile products	0.543	4
24	Lumber and wood products	0.639	11
25	Furniture and fixtures	0.695	16
26	Paper and allied products	0.554	6
27	Printing and publishing	0.692	15
28	Chemicals and allied products	0.404	1
29	Petroleum and coal products	0.500	2
30	Rubber and miscellaneous plastics products	0.835	20
31	Leather and leather products	0.663	14
32	Stone, clay, and glass products	0.551	5
33	Primary metal industries	0.604	8
34	Fabricated metal products	0.748	17
35	Industrial machinery and equipment	0.614	10
36	Electronic and other electric equipment	0.610	9
37	Motor vehicles and equipment	0.764	18
38	Instruments and related products	0.645	12
39	Miscellaneous manufacturing industries	0.649	13

1)The fraction of irreversible capital expenditures (based on dollar amounts) is calculated for each industry according to Table B1. Industries are ranked according to this measure to generate an Irreversibility Index. The higher the index, the more irreversible is the industry.

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Table 1a: Descriptive Statistics (1964-1999)

Variable	Mean	Std. Dev.	Minimum	Median	Maximum
I/K	0.2333	0.2049	0.0135	0.1813	1.2982
Tobin's q	1.4716	0.9307	0.6077	1.1877	6.5162
MPK	0.1514	0.1498	0.0123	0.1091	1.0149
CF/K	0.3023	0.6770	-3.5076	0.2734	2.9051
Assets (real)	17.7545	51.4785	0.0397	2.2553	374.6321
D/(D+E)	0.2599	0.2134	0.0000	0.2193	0.8333
Total Uncertainty: σ_{it}	0.4395	0.2536	0.1439	0.3644	1.4591
Market Uncertainty (b): $\beta_{it}\sigma_{Mt}$	0.0899	0.0646	-0.0487	0.0799	0.2967
Firm-Specific Uncertainty (b): $\sigma_{\varepsilon it}$	0.4245	0.2563	0.1327	0.3472	1.4530
Market Uncertainty (c): $\beta_{it}\sigma_{Mt}$	0.0899	0.0646	-0.0487	0.0799	0.2967
Industry Uncertainty: $\gamma_{it}\sigma_{It}$	0.0605	0.0841	-0.0979	0.0404	0.3853
Firm-Specific Uncertainty (c): $\sigma_{\varepsilon it}$	0.4036	0.2682	0.0184	0.3316	1.4490
Number of Firms	2901				
Number of Observations	29639				

1) Market Uncertainty (b) and Firm-Specific Uncertainty (b) correspond to the market decomposition of firm returns.
2) Market Uncertainty (c) and Firm-Specific Uncertainty (c) correspond to the orthogonal market and industry decomposition of firm returns.

Table 1b: Sample Correlations

Variable	I/K	Tobin's q	MPK	Cash Flow	D/(D+E)	σ_{it}	$\beta_{it}\sigma_{Mt}$ (b)	$\sigma_{\varepsilon it}$ (b)	$\beta_{it}\sigma_{Mt}$ (c)	$\gamma_{it}\sigma_{It}$
I/K	1									
Tobin's q	0.2302	1								
MPK	0.4413	0.056	1							
Cash Flow	0.2676	0.081	0.2979	1						
D/(D+E)	-0.251	-0.4675	-0.0495	-0.2134	1					
σ_{it}	0.0707	-0.0365	0.1444	-0.2015	0.1687	1				
$\beta_{it}\sigma_{Mt}$ (b)	0.0621	0.0544	-0.0437	-0.0061	0.0575	0.0917	1			
$\sigma_{\varepsilon it}$ (b)	0.0667	-0.0431	0.1499	-0.202	0.1681	0.997	0.025	1		
$\beta_{it}\sigma_{Mt}$ (c)	0.0621	0.0544	-0.0437	-0.0061	0.0575	0.0917	1	0.025	1	
$\gamma_{it}\sigma_{It}$	-0.0398	0.0414	-0.0511	0.023	0.0568	-0.0874	0.2267	-0.1062	0.2267	1
$\sigma_{\varepsilon it}$ (c)	0.0689	-0.0531	0.1486	-0.1969	0.1568	0.9694	-0.0071	0.975	-0.0071	-0.2719

1) Tobin's q, MPK, cash flow and the debt-ratio are lagged values consistent with the empirical specification.

Table 2: Base Regressions

Variable	(a)	(b)	(c)	(a)	(b)	(c)
Tobin's q				0.0132	0.0120	0.0124
				(2.17)	(1.99)	(2.05)
MPK_{t-1}				0.7771	0.8000	0.8071
				(7.31)	(7.56)	(7.51)
$(CF/K)_{t-1}$				0.0326	0.0322	0.0322
				(3.29)	(3.24)	(3.20)
Total Uncertainty: σ_{it}	-0.4752			-0.1939		
	-(11.53)			-(4.10)		
Market Uncertainty: $\beta_{it}\sigma_{Mt}$		0.6150	0.6141		-0.0300	0.0130
		(4.14)	(3.99)		-(0.22)	(0.09)
Industry Uncertainty: $\gamma_{it}\sigma_{It}$			-0.1441			-0.1784
			-(1.32)			-(2.09)
Firm-Specific Uncertainty: $\sigma_{\varepsilon it}$		-0.5381	-0.5193		-0.1882	-0.1677
		-(11.77)	-(11.48)		-(3.72)	-(3.38)
F(n,2721)	16.81	16.41	16.25	25.11	24.51	23.85
p-value	0	0	0	0	0	0
Root MSE	0.1248	0.1257	0.1256	0.1125	0.1125	0.1127
No. of Firms	2722	2722	2722	2722	2722	2722
No. of observations	19579	19579	19579	19579	19579	19579

1) The dependent variable is I/K. Model (a) uses total volatility, model (b) corresponds to the market decompostion of firm returns, and model (c) corresponds to the orthogonal market and industry decompostion of firm returns.

2) Estimation is by instrumental variables (2SLS). Instruments are lagged values of all the right-hand side variables plus lagged Sales/K, lagged I/K, and year dummies. Firm fixed effects are eliminated according to Arellano and Bover (1995).

3) Robust standard errors are calculated that allows for correlation within firms. T-statistics are in parenthesis

4) n=33+number of regressors.

Table 3: MPK (Marginal Profitability of Capital) Regressions

Variable	(a)	(b)	(c)	(a)	(b)	(c)
Tobin's q				0.0017	0.0003	0.0004
				(0.65)	(0.12)	(0.14)
MPK_{t-1}				0.3383	0.3319	0.3226
				(6.83)	(6.65)	(6.33)
$(CF/K)_{t-1}$				0.0113	0.0090	0.0098
				(2.42)	(1.90)	(2.01)
Total Uncertainty: σ_{it}	-0.2332			-0.1144		
	-(9.03)			-(4.73)		
Market Uncertainty: $\beta_{it}\sigma_{Mt}$		0.6008	0.5665		0.3682	0.3495
		(5.86)	(5.45)		(5.47)	(5.02)
Industry Uncertainty: $\gamma_{it}\sigma_{It}$			0.0077			-0.0003
			(0.10)			-(0.01)
Firm-Specific Uncertainty: $\sigma_{\varepsilon it}$		-0.2907	-0.2841		-0.1536	-0.1505
		-(9.22)	-(8.71)		-(5.65)	-(5.65)
F(n,2721)	12.29	11.03	10.56	27.54	24.4	23.11
p-value	0	0	0	0	0	0
Root MSE	0.0582	0.0632	0.0632	0.0410	0.0439	0.0442
No. of Firms	2722	2722	2722	2722	2722	2722
No. of observations	19579	19579	19579	19579	19579	19579

1) The dependent variable is MPK. Model (a) uses total volatility, model (b) corresponds to the market decompostion of firm returns, and model (c) corresponds to the orthogonal market and industry decompostion of firm returns.

2) Estimation is by instrumental variables (2SLS). Instruments are lagged values of all the right-hand side variables plus lagged Sales/K, lagged I/K, and year dummies. Firm fixed effects are eliminated according to Arellano and Bover (1995).

3) Robust standard errors are calculated that allows for correlation within firms. T-statistics are in parenthesis

4) n=33+number of regressors.

Table 4: Irreversible Investment Regressions

Variable	Irreversible Investments (a)	(b)	(c)	Reversible Investments (a)	(b)	(c)
Tobin's q	0.0245	0.0247	0.0242	0.0027	0.0014	0.0013
	(2.56)	(2.53)	(2.49)	(0.34)	(0.18)	(0.17)
MPK_{t-1}	0.6960	0.7252	0.7208	0.8840	0.9040	0.9246
	(5.32)	(5.61)	(5.56)	(4.93)	(5.06)	(4.91)
$(CF/K)_{t-1}$	0.0377	0.0366	0.0359	0.0297	0.0300	0.0303
	(3.07)	(2.99)	(2.91)	(1.82)	(1.84)	(1.82)
Total Uncertainty: σ_{it}	-0.1096			-0.2468		
	-(1.61)			-(3.58)		
Market Uncertainty: $\beta_{it}\sigma_{Mt}$		-0.0665	0.0865		-0.0997	-0.1137
		-(0.25)	(0.32)		-(0.60)	-(0.68)
Industry Uncertainty: $\gamma_{it}\sigma_{It}$			-0.1984			-0.1420
			-(1.83)			-(0.79)
Firm-Specific Uncertainty: $\sigma_{\varepsilon it}$		-0.0872	-0.0965		-0.2416	-0.2099
		-(1.07)	-(1.30)		-(3.42)	-(2.67)
F(n,k)	16.7	16.28	15.76	11.93	11.65	11.34
p-value	0	0	0	0	0	0
Root MSE	0.1154	0.1156	0.1159	0.1108	0.1111	0.1114
No. of Firms	1432	1432	1432	1376	1376	1376
No. of observations	9362	9362	9362	10217	10217	10217

1) The sub-samples are created according to the degree of irreversibility of invested capital at the 2-digit SIC level. See Appendix B for more details.

2) The dependent variable is I/K. Model (a) uses total volatility, model (b) corresponds to the market decompostion of firm returns, and model (c) corresponds to the orthogonal market and industry decompostion of firm returns.

3) Estimation is by instrumental variables (2SLS). Instruments are lagged values of all the right-hand side variables plus lagged Sales/K, lagged I/K, and year dummies. Firm fixed effects are eliminated according to Arellano and Bover (1995).

4) Robust standard errors are calculated that allows for correlation within firms. T-statistics are in parenthesis

5) n=33+number of regressors.k=number of firms-1

Table 5: Industry Concentration Regressions

Variable	Less Competitive Firms (a)	(b)	(c)	More Competitive Firms (a)	(b)	(c)
Tobin's q	0.0178	0.0161	0.0158	0.0142	0.0138	0.0140
	(1.79)	(1.65)	(1.63)	(1.63)	(1.59)	(1.60)
MPK_{t-1}	0.4744	0.4915	0.4965	1.0511	1.0569	1.0727
	(3.31)	(3.43)	(3.45)	(4.49)	(4.52)	(4.64)
$(CF/K)_{t-1}$	0.0459	0.0445	0.0455	0.0238	0.0231	0.0221
	(3.14)	(2.99)	(3.05)	(0.75)	(0.74)	(0.70)
Total Uncertainty: σ_{it}	-0.4370			-0.0824		
	-(4.80)			-(1.14)		
Market Uncertainty: $\beta_{it}\sigma_{Mt}$		-0.0145	0.0897		0.0888	0.1068
		-(0.07)	(0.42)		(0.45)	(0.54)
Industry Uncertainty: $\gamma_{it}\sigma_{It}$			-0.3041			-0.1598
			-(2.13)			-(1.19)
Firm-Specific Uncertainty: $\sigma_{\varepsilon it}$		-0.4468	-0.4475		-0.0953	-0.0808
		-(4.32)	-(4.37)		-(1.12)	-(0.98)
F(n,k)	12.53	12.17	11.84	10.58	10.35	10.19
p-value	0	0	0	0	0	0
Root MSE	0.0933	0.0931	0.0940	0.0989	0.0987	0.0992
No. of Firms	779	779	779	894	894	894
No. of observations	7130	7130	7130	7056	7056	7056

1) The sub-samples are created according to the degree of competitiveness of the firm in a four digit SIC industry as measured by industry concentration ratios from the 1992 Census of Manufactures.

2) The dependent variable is I/K. Model (a) uses total volatility, model (b) corresponds to the market decompostion of firm returns, and model (c) corresponds to the orthogonal market and industry decompostion of firm returns.

3) Estimation is by instrumental variables (2SLS). Instruments are lagged values of all the right-hand side variables plus lagged Sales/K, lagged I/K, and year dummies. Firm fixed effects are eliminated according to Arellano and Bover (1995).

4) Robust standard errors are calculated that allows for correlation within firms. T-statistics are in parenthesis

Table 6: Size Regressions Based on Real Total Assets

Variable	Large Firms (a)	Large Firms (b)	Large Firms (c)	Small Firms (a)	Small Firms (b)	Small Firms (c)
Tobin's q	0.0219	0.0216	0.0219	0.0056	0.0055	0.0055
	(3.45)	(3.41)	(3.47)	(0.43)	(0.42)	(0.43)
MPK_{t-1}	0.8812	0.8892	0.8904	0.6757	0.6743	0.6656
	(6.91)	(6.92)	(7.00)	(4.98)	(4.99)	(4.84)
$(CF/K)_{t-1}$	0.0398	0.0384	0.0402	0.0300	0.0329	0.0333
	(2.79)	(2.68)	(2.78)	(2.63)	(2.76)	(2.79)
Total Uncertainty: σ_{it}	-0.2365			-0.1518		
	-(5.03)			-(2.41)		
Market Uncertainty: $\beta_{it}\sigma_{Mt}$		0.0681	0.1284		-0.4257	-0.4007
		(0.59)	(1.07)		-(0.83)	-(0.76)
Industry Uncertainty: $\gamma_{it}\sigma_{It}$			-0.2320			-0.1318
			-(2.69)			-(0.57)
Firm-Specific Uncertainty: $\sigma_{\varepsilon it}$		-0.2689	-0.2389		-0.1595	-0.1579
		-(5.02)	-(4.57)		-(2.48)	-(2.61)
F(n,k)	25.17	24.28	23.63	5.61	5.39	5.26
p-value	0	0	0	0	0	0
Root MSE	0.0893	0.0893	0.0896	0.1546	0.1579	0.1581
No. of Firms	1361	1361	1361	1361	1361	1361
No. of observations	13762	13762	13762	5817	5817	5817

1) The full sampe is divided at the median average-firm size measured by total real assets.

2) The dependent variable is I/K. Model (a) uses total volatility, model (b) corresponds to the market decompostion of firm returns, and model (c) corresponds to the orthogonal market and industry decompostion of firm returns.

3) Estimation is by instrumental variables (2SLS). Instruments are lagged values of all the right-hand side variables plus lagged Sales/K, lagged I/K, and year dummies. Firm fixed effects are eliminated according to Arellano and Bover (1995).

4) Robust standard errors are calculated that allows for correlation within firms. T-statistics are in parenthesis

Table 7: Leverage

Variable	Unlevered Volatility (a)	Unlevered Volatility (b)	Unlevered Volatility (c)	Levered Volatility (a)	Levered Volatility (b)	Levered Volatility (c)	Unlevered Firms (a)	Unlevered Firms (b)	Unlevered Firms (c)
Tobin's q	0.0103	0.0090	0.0091	0.0065	0.0046	0.0053	0.0114	0.0099	0.0105
	(1.76)	(1.56)	(1.57)	(1.08)	(0.76)	(0.87)	(1.15)	(0.98)	(1.06)
MPK_{t-1}	0.7958	0.8200	0.8294	0.7222	0.7643	0.7760	0.7532	0.7763	0.7919
	(7.54)	(7.82)	(7.79)	(6.90)	(7.39)	(7.30)	(4.22)	(4.48)	(4.43)
$(CF/K)_{t-1}$	0.0298	0.0294	0.0289	0.0335	0.0319	0.0315	0.0259	0.0271	0.0254
	(2.91)	(2.88)	(2.79)	(3.33)	(3.19)	(3.06)	(1.72)	(1.78)	(1.64)
$D/(D+E)_{t-1}$	-0.0600	-0.0642	-0.0715	-0.1724	-0.1659	-0.1655			
	-(2.70)	-(2.83)	-(3.12)	-(7.11)	-(6.55)	-(6.57)			
Total Uncertainty : σ_{it}	-0.1542			-0.3660			-0.3710		
	-(2.95)			-(4.17)			-(2.26)		
Market Uncertainty : $\beta_{it}\sigma_{Mt}$		-0.0569	-0.0088		0.0074	0.0760		-0.2724	-0.1479
		-(0.41)	-(0.06)		(0.04)	(0.38)		-(0.79)	-(0.41)
Industry Uncertainty : $\gamma_{it}\sigma_{It}$			-0.1826			-0.3590			-0.4330
			-(2.13)			-(2.80)			-(1.73)
Firm-Specific Uncertainty : $\sigma_{\varepsilon it}$		-0.1421	-0.1173		-0.3395	-0.2885		-0.3522	-0.3053
		-(2.52)	-(2.11)		-(3.56)	-(3.09)		-(2.02)	-(1.75)
F(n,k)	25.83	25.29	24.64	25.65	24.5	24.66	6.24	6.16	5.93
p-value	0	0	0	0	0	0	0	0	0
Root MSE	0.1119	0.1121	0.1124	0.1130	0.1124	0.1127	0.1473	0.1481	0.1488
No. of Firms	2722	2722	2722	2722	2722	2722	898	898	898
No. of observations	19579	19579	19579	19579	19579	19579	5318	5318	5318

1) The dependent variable is I/K. Model (a) uses total volatility, model (b) corresponds to the market decompostion of firm returns, and model (c) corresponds to the orthogonal market and industry decompostion of firm returns.

2) Unlevered volatility measures are calculated by multiplying volatility by E/(D+E). The sub-sample of unlevered firms is the bottom third (33rd percentile) of firms in terms of leverage with a mean leverage ratio of 4.3 %.

3) Estimation is by instrumental variables (2SLS). Instruments are lagged values of all the right-hand side variables plus lagged Sales/K, lagged I/K, and year dummies.

4) Robust standard errors are calculated that allows for correlation within firms. T-statistics are in parenthesis

5) n=33+number of regressors.k=number of firms-1