Investment Sensitivity to Conditional Uncertainty: Nesting Alternative Theoretical Specifications

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Abstract

We present an empirical model for the investment-uncertainty relationship that encompasses the frictionless neoclassical benchmark, as well as its friction-including variants, taking the form of imperfect competition, irreversibility and decreasing returns-to-scale. We generate conditional volatility in a panel framework applying a Pooled Panel GARCH method. We document significant nonlinearities, since the magnitude and sign of investment's sensitivity to uncertainty change dramatically across alternative economic environments, as defined by different combinations of irreversibility, market power, and returns-to-scale. In general, as the severity of deviations from the benchmark progresses, investment elasticity eventually crosses the zero line and attains negative values.

Keywords: Investment, Irreversibility, Market Power, Returns-to-Scale, Uncertainty

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1. Introduction

A fundamental question that has dominated the research agenda of macroeconomics during the past two decades is the sign of the investment-uncertainty relationship. As it turns out, the answer to this question critically depends on model protocol. Indicative of this dependence is the different sign advocated by the two currently dominant literatures.

At the one end, one finds the frictionless neoclassical model whose core result is that higher uncertainty boosts investment (Oi, 1961; Hartman, 1972, 1976; Abel, 1983). In this context, the intertemporal linkage between current and future investment breaks down. Consequently, higher uncertainty inducing higher expected marginal profitability of capital, leads to increased current investment.

Departures from the frictionless environment may take several forms. Focusing on a model where all benchmark assumptions are relaxed, leads to the conclusion that uncertainty affects investment negatively. This result may be brought about by a less than infinite elasticity of demand, which reinstates the temporal dependence of investment through either lower convexity of the profit function to uncertainty, or the negative relationship between the markup and marginal profitability of capital, for a given increase in capital (Caballero, 1991). Decreasing returns-to-scale also lead to a convexity of the profit function with respect to the uncertain variable that increases the likelihood of a negative investment-uncertainty relationship (Caballero, 1991). Moreover, irreversibility and/or asymmetries of adjustment costs lead to a heterogeneous impact of favourable and adverse shocks, which makes optimal to 'buy' some insurance in the form of either less initial investment or deferring investment (McDonald and Siegel, 1986; Caballero, 1991; Dixit and Pindyck, 1994). As it becomes apparent, the interplay of these structural factors is of paramount importance for the underlying relationship. The empirical literature has devoted huge resources on investigating the sign of the investment-uncertainty relationship. However, as yet, no empirical study has incorporated in a single model all the above mentioned structural factors. The lack of such an empirical model causes two problems: a) one cannot nest competing theories in an encompassing empirical model, and b) one cannot unequivocally attribute the estimated sign to a specific factor, unless the model conditions on all three.

Our study makes a twofold contribution to the existing literature. First, we present an empirical model for the investment-uncertainty relationship that nests the frictionless neoclassical benchmark, as well as its friction-including variants, taking the form of imperfect competition, irreversibility and decreasing returns-to-scale. This is the first attempt, to the best of our knowledge, to jointly allow for all three deviations from the benchmark. Second, using the recently developed method of Pooled Panel GARCH (PP-GARCH hereafter) we generate volatility in a panel framework. This uncertainty metric has the distinct advantage, apart from being crosssectionally and time-varying, of capturing conditional uncertainty, thereby reflecting the level of uncertainty at the time of decision making.

2. A Brief Review of the Literature

2.1. The Neoclassical Benchmark

One strand of the investment-uncertainty literature assuming perfect competition, constant returns-to-scale, fully reversible capital, symmetric convex adjustment costs, and risk-neutral behaviour by the firm¹ (Oi, 1961; Hartman, 1972, 1976; Abel, 1983) predicts a positive impact of uncertainty on investment. The positive response of investment to uncertainty arises from the convexity of the marginal revenue product of capital with respect to the uncertainty variable. In other words, a mean-preserving increase in the distribution of the uncertain variable raises investment (Hartman, 1972, 1976; Abel, 1983). This vitally relies on the assumption that the decision maker faces an infinitely elastic demand in the relevant product market, which results in an optimal investment choice that does not depend on capital stock. Consequently, diachronic links are absent and investment responds positively to a greater uncertainty stimulus. In addition, there is no sunkness of capital, *i.e.* full reversibility, permitting complete recovery of undepreciated capital values. Full reversibility may be achieved either by a sufficient degree of substitutability between labour and capital, where the former absorbs the effect of shocks (Oi, 1961; Hartman, 1972, 1976; Lee and Shin, 2000), or the existence of highly active second-hand (resale) or leasing markets for capital, that ensure ease of disposing/acquiring capital in the occurrence of a shock (Kessides, 1990; Worthington, 1995).

2.2. Deviations from the Benchmark

Caballero (1991) elegantly shows that as the elasticity of demand is reduced, the convexity of the marginal profitability of capital with respect to uncertainty is decreased. Furthermore, he demonstrates that under imperfect competition the firm's incentive to invest is diminished, since increasing output affects negatively the market price (downward sloping demand curve) and the marginal profitability of capital is inversely related to the markup (market power) for a given increase in capital. The combination of these two effects erodes the positive investment-uncertainty linkage.

Another strand of the literature emphasizes irreversibility of capital leading to a marginal revenue product of capital being a concave function of the uncertainty variable (Abel and Eberly, 1994, 1999; Dixit and Pindyck, 1994; Eberly, 1997). Indeed, in the presence of fixed or sunk costs, firms may be reluctant to invest because of the possibility that they may wish to sell their installed capital in the future but will be able to reclaim little, if any, of the undepreciated value (Chirinko and Schaller, 2002). A similar conclusion has been reached by the Real Options Theory, which posits that in the presence of higher uncertainty, the firm may find it more prudent to postpone current investment until part of the uncertainty resolves. In other words, as the 'option' value of waiting increases, the opportunity cost of investment increases too, creating a negative effect of uncertainty on investment (McDonald and Siegel, 1986; Pindyck, 1988; Dixit and Pindyck, 1994; Abel *et al*, 1996; Caballero and Pindyck, 1996).

2.3. Review of Empirical Evidence

There is a vast empirical literature addressing a wide variety of questions on the issue. A group of studies split the sample according to structural indicators affecting the investment-uncertainty relationship's sign, either in terms of Market Power (Ghosal and Loungani, 1996; Guiso and Parigi, 1999), or in terms of Irreversibility (Leahy and Whited, 1996; Guiso and Parigi, 1999; Goel and Ram, 1999, 2001; Driver *et al.*, 2003; Drakos, 2006).

In some more detail, Ghosal and Loungani (1996) explore the effect of market structure by splitting their sample between sectors with low and high market power and between sectors with low and high irreversibility. They conclude that uncertainty lowers investment in highly competitive industries and in industries characterised by a higher degree of irreversibility. Leahy and Whited (1996) showed that conditional uncertainty exerts a strong negative influence on investment which is mainly driven by the degree of irreversibility. Guiso and Parigi (1999) investigate the individual effects of market structure and irreversibility by splitting their sample, first between firms with high and low market power, and then by high and low irreversibility. Their findings indicate that the negative impact of uncertainty is substantially stronger when firms cannot easily dispose their excess capital stock in second-hand markets. Moreover, uncertainty is more harmful for firms facing inelastic demand.

Goel and Ram (2001) exploit differential reversibility by distinguishing between R&D and non-R&D investment, where the former is assumed to be more irreversible. According to their findings for R&D investment, uncertainty has a strongly significant negative sign, however when non-R&D outlays are used, it carries the 'wrong' sign. Driver *et al.* (2003) compared investment in machinery versus new buildings, conducting their analysis assuming that machinery is characterised by higher specificity and thus higher irreversibility. They conclude that irreversibility amplifies the negative influence of uncertainty on fixed investment. Finally, Drakos (2006) utilising investment spending across different types of capital goods, considers a broader asset type classification in terms of the degree of irreversibility, concluding that higher uncertainty is negatively affecting investment, and also that the negative impact of uncertainty is an increasing function of the degree of irreversibility.

3. Data Issues

3.1. Definition of Variables

We use semi-aggregated firm balance sheets and profit and loss accounts for 10 manufacturing sectors², each sector is divided into 3 size classes, for *Austria*, *Belgium*, *Italy*, *France*, *Netherlands*, *Germany*, *Finland*, *Spain*, *Portugal*, *Sweden*, and *Denmark*, for the period 1987 to 2002 provided by the Bank for the Accounts of Companies Harmonised. Thus the basic decision unit³ corresponds to a given sector from a given country and of given size class. We constructed the following variables:

Investment; $\left(\frac{I}{K}\right)_{i,t}$, (Acquisitions of Tangible Fixed Assets - Sales and Disposals

divided by the beginning-of-period capital stock, K), growth rate of sales; $\Delta \log \left(\frac{S}{K}\right)_{i,t}$, $\left(\frac{S}{K}\right)$: the ratio of Turnover to beginning-of-period capital stock), cash

flow; $\left(\frac{CF}{K}\right)_{i,t}$, (Gross Operating Profit over beginning-of-period capital stock),

 $ECM_{i,t} \equiv (k - y)_{i,t}$ (the difference of the logarithm of Total Assets and the logarithm of Turnover).

We compute the price-cost margin,

$$PCM = \left(\frac{\text{value of sales - payroll - cost of materials}}{\text{value of sales}}\right), \text{ classifying a decision unit as}$$

having more (less) market power when its profit margin is above (below) the median value, PCM_t^{med} , obtained from the distribution of all decision units' *PCM* in a given year (Domowitz *et al.*, 1987). We construct the market power dummy defined as:

$$MP_{i,t} = \begin{cases} 1, \text{ if } PCM_{i,t} > PCM_t^{med} \\ 0, \text{ if } PCM_{i,t} < PCM_t^{med} \end{cases}$$
(1)

We classify a sector as facing more (less) irreversible investment when the variance of its labour-capital ratio is below (above) the median value, $Var\left(\frac{L}{K}\right)_{t}^{med}$, obtained from the distribution of all sectors for a given year (Leahy and Whited,

obtained from the distribution of all sectors for a given year (Leahy and Whited, 1996). Hence, the irreversibility dummy is defined as:

$$IRR_{s,t} = \begin{cases} 1, \text{ if } Var\left(\frac{L}{K}\right)_{s,t} < Var\left(\frac{L}{K}\right)_{t}^{med} \\ 0, \text{ if } Var\left(\frac{L}{K}\right)_{s,t} > Var\left(\frac{L}{K}\right)_{t}^{med} \end{cases}$$
(2)

Assuming a log-linear Cobb-Douglas production function, $\ln(Q) = \alpha + \beta \ln(K) + \gamma \ln(L)$, where Q denotes output, β, γ stand for the constant capital and labour share respectively, and finally α is a constant that typically captures the level of available technology. We partition the sample according to whether the production function exhibits constant $(\beta + \gamma = 1)$ or, decreasing returnsto-scale $(\beta + \gamma < 1)$, based on the estimates of factor elasticities after applying (time series) regression analysis for each decision unit. We conduct a Wald test to assess the type of returns-to-scale and subsequently, utilizing the inference from this hypothesis testing we construct a dummy defined as:

$$RS_{i} = \begin{cases} 1, \text{ if } \beta + \gamma < 1\\ 0, \text{ if } \beta + \gamma = 1 \end{cases}$$
(3)

3.2. Measuring Uncertainty

The literature identifies various sources of uncertainty that maybe relevant for investment decision making. When focusing on aggregate investment, uncertainty about taxes, interest rates, inflation and exchange rates has been considered. On more disaggregate levels (sector or firm) theory puts forward uncertainty stemming from demand, product / input prices, profits, sales. In addition, researchers focusing on listed firms have employed uncertainty measures based on stock return volatility.

In our study we will consider sector-specific uncertainty, $(\sigma_{i,t})$, proxied by the conditional volatility of Net Operating Profits. We adopt a profits-based uncertainty because it is an amalgamation of uncertainties generated by sales, costs, demand etc. The actual metric is constructed by estimating a Pooled Panel GARCH model. Let us define Z as the variable corresponding to the source of uncertainty. Then, we estimate the following model:

$$Z_{i,t} = \beta_0 + \beta_1 Z_{i,t-1} + \beta_2 Z_{i,t-2} + \eta_{i,t}$$
(4)

where β 's stand for estimable parameters and η_t is a disturbance term.

In particular, we assume that $\eta_{i,t} \sim N[0,\Omega_{i,t}]$, *i.e.* are multivariate normal error terms with a time-varying conditional variance-covariance matrix producing a Pooled Panel GARCH model (Cermeno and Grier, 2005). The variance-covariance matrix $\Omega_{i,t}$ is time-dependent and its diagonal and off-diagonal elements are given by the following equations:

$$\sigma_{i,t}^{2} = \alpha + \sum_{n=1}^{p} \delta_{n} \sigma_{i,t-n}^{2} + \sum_{m=1}^{q} \gamma_{m} \eta_{t-m}^{2}, \text{ for } i = 1,...N$$
(5)

$$\sigma_{i,j,t} = \kappa + \sum_{n=1}^{p} \lambda_n \sigma_{i,j,t-n} + \sum_{m=1}^{q} \rho_m \eta_{i,t-m} \eta_{j,t-m}, \text{ for } i \neq j$$
(6)

Although multivariate GARCH models are available they are not practical for most panel applications because they require the estimation of a large number of parameters. In contrast, a PP-GARCH estimation by imposing common dynamics on the variance-covariance process across cross-sectional units reduces the number of parameters dramatically ensuring parsimony. Furthermore, the PP-GARCH model does not imply constant cross-sectional correlation over time. Table 1 reports the estimation results.

[Table 1]

Alternative specifications of the PP-GARCH family were estimated and the preferred model was chosen using the Akaike Information Criterion (Akaike, 1969), which led to the adoption of a PP-ARCH(2) model. The coefficients in the conditional variance equation are significant and suggest a highly persistent volatility, consistent with volatility clustering. The fitted values from the volatility equation are recovered and used as proxies for uncertainty. Note that this measure of volatility possesses the desirable properties of being conditional, as well as being cross-sectionally and time-varying.

4. An Empirical Model for Investment: Encompassing Alternative Theories

In the present study we construct an empirical model that jointly accounts for all factors affecting the sign of the investment-uncertainty relationship. In particular, an accelerator type model is employed, reflecting the information content of sales growth for future investment profitability (Abel and Blanchard, 1986), augmented by an error correction model underlying the presence of adjustment costs that may impede full adjustment of the actual capital stock to the desired level (Bond *et al.*, 2003), controlling for past investment behaviour, cash flow and time effects. Our empirical specification corresponds to the following model:

$$\left(\frac{I}{K}\right)_{i,t} = \delta_0 + \delta_1 \left(\frac{I}{K}\right)_{i,t-1} + \delta_2 \Delta \log\left(\frac{S}{K}\right)_{i,t} + \delta_3 \left(\frac{CF}{K}\right)_{i,t} + \delta_4 \left(ECM\right)_{i,t-2} + \delta_{unc} \left(\sigma\right)_{i,t} + \delta_{mp} \left(\sigma^*MP\right)_{i,t} + \delta_{irr} \left(\sigma^*IRR\right)_{i,t} + \delta_{rs} \left(\sigma^*RS\right)_{i,t} + \sum_{t=1987}^{2002} \tau_t \left(\text{time dummies}\right) + \varepsilon_{i,t}$$

$$(7)$$

Where, $\delta's, \tau's$ are unknown constant parameters to be estimated and ε is an unobserved spherical disturbance term. Estimating the model in this form we anticipate that lagged investment is positively correlated with current investment, indicating persistence in investment that would be consistent with *time-to-build* effects. Growth rate of sales is also expected to have a positive effect to investment opportunities as proposed by the Sales Accelerator model (Abel and Blanchard, 1986). The coefficient of cash flow is expected to be positive, reflecting future investment opportunities and/or the presence of liquidity constraints that arise due to capital market imperfections (Fazzari *et al*, 1988). Finally, error-correcting behaviour requires that the coefficient on the term $ECM_{i,t-2} \equiv (k-y)_{i,t-2}$ is negative, so when capital stock is above (below) the desired level, investment is reduced (increased).

One of the benefits estimating this model is that it accommodates the assessment of each factor's partial impact, as measured by the parameters δ_{irr} , δ_{rs} , δ_{mp} . What is more important, this model nests, among others, the two extreme cases emerging from the dyadic nature of the dummy variables. To put it more formally, consider the benchmark case of 'low' market power, constant returns-to-scale and 'low' irreversibility of capital, which is analogous to a Hartman-Abel environment. In such a case, all three dummies attain a value of zero and therefore, the sensitivity of investment to uncertainty is given by:

$$\left[\frac{\partial \left(I/K\right)}{\partial (\sigma)}\right]_{MP=IRR=RS=0} = \delta_{unc}$$
(8)

Recall that in such an environment, economic theory predicts that higher uncertainty affects investment positively and therefore restricts the *a priori* sign of the above derivative to be positive; $\delta_{unc} > 0$.

In contrast, if one considers the other end of the spectrum where all three dummies attain the value of unity, *i.e.* 'high' market power, 'high' irreversibility and decreasing returns-to-scale, then the sensitivity of investment to uncertainty is given by:

$$\left[\frac{\partial \left(\frac{I}{K}\right)}{\partial (\sigma)}\right]_{MP=IRR=RS=1} = \delta_{unc} + \delta_{irr} + \delta_{rs} + \delta_{mp}$$
(9)

In the presence of uncertainty, the individual partial effects of each factor tend to be negative. For instance, the likelihood of a negative impact of uncertainty on investment is monotonic in the degree of market power (Caballero, 1991; Sakellaris, 1994). In addition, it has been demonstrated that the investment trigger point is above the standard Jorgensonian user-cost of capital reflecting the irreversibility premium (Dixit and Pindyck, 1994; Abel and Eberly, 1995, 1996; Chirinko and Schaller, 2002). Moreover, decreasing returns-to-scale affect the relationship in a similar manner as imperfect competition does, leading to a negative impact of uncertainty (Caballero, 1991). Thus, we expect the sum of these coefficients to be significantly negative; $\delta_{unc} + \delta_{irr} + \delta_{rs} + \delta_{mp} < 0$.

A thorough reading of the literature reveals the highly complex nature of the underlying relationship due to the interplay between market power, irreversibility and returns-to-scale. The sign depends on the profile of the environment within which investment decisions are made, whose fundamental characteristics are summarized by the triplet: [degree of market power, degree of irreversibility, type of technology].

Using the dyadic nature of dummies (zero/one) that identify the absence or presence of specific deviations from the benchmark, one may effectively test for the investment derivative with respect to uncertainty across alternative environments. Essentially, this allows us to 'draw a map' of the investment sensitivity function to uncertainty across various structural characteristics of the environment in which decisions makers operate. Caballero (1991) offers significant insights regarding investment's response for these intermediate cases. For instance, Caballero's work clearly shows that single-sourced deviations may lead to a negative sign of the underline derivative, when imperfect competition or decreasing returns-to-scale are considered. In contrast, asymmetry of adjustment costs alone is not sufficient to render a negative investment-uncertainty relationship. When paired deviations are considered in Caballero's theoretical work, a negative sign is very likely. Utilizing the effects resulting from the individual deviations one may infer the joint effect for the resulting pairs. For instance, we expect that the combination of inelastic demand and decreasing returns will produce the largest negative impact, followed either by inelastic demand combined with irreversibility, or decreasing returns coupled with irreversibility. Hence, moving away from the benchmark case, the positive effect of uncertainty on investment gradually dies out and ultimately turns negative. Needless to say, the highest negative impact is expected to be encountered when all the three sources of deviation are in operation.

5. Empirical Methodology and Results

The parameters of equation (7) are estimated by applying the Arellano and Bond (1991) Generalized Method of Moments (GMM) dynamic panel technique. The actual estimation is based on the first-differences of all variables included in the model, which results in a new disturbance term exhibiting, by construction, first-order autocorrelation. The statistical adequacy of the model is established when two conditions are met: (i) the generated residuals do not exhibit second-order autocorrelation, property that is checked by the use of the m_2 statistic as developed by Arellano and Bond (1991), and (ii) the over-identifying restrictions are not rejected, a condition checked by applying the Sargan (1958) test. In Table 2 we report the estimation results for model (7).

[Table 2]

The model satisfies the over-identifying restrictions as well as the insignificance of the second-order autocorrelation of residuals and therefore, can be used to conduct inferences on the recovered parameters. The coefficients of the control variables are in accordance with our priors. Of particular importance is the speed of adjustment parameter, which is significantly negative, but of a small absolute

magnitude suggesting a very sluggish response to deviations from the frictionless capital stock.

When the three dummies attain the value of zero, investment sensitivity to uncertainty is encapsulated in the coefficient δ_{unc} , whose estimate is significantly positive (point estimate 0.43, p-value 0.00). This finding provides empirical evidence in favour of the theoretical prediction obtained in an *a la* Hartman-Abel environment.

We proceed with the investigation of the behaviour of investment response across intermediate cases. In particular, we consider alternative deviations from the Hartman-Abel benchmark where each time the deviation stems from different sources. The coefficient of every interaction term is highly significant and carries the 'correct' negative sign. Recall that each interaction term essentially applies a dichotomization of decision makers based on their characteristics in terms of the dummies. Thus, significance of the interaction coefficients indicates that uncertainty tends to exert a non-uniform impact on investment across decision makers that face either different degrees of irreversibility, or market power, or production function homogeneity. For ease of exposition we provide the following table that shows the combined investment derivative and its statistical significance for each case.

[Table 3]

A number of important and intuitive inferences can be drawn. First, none of the single-sourced deviations is sufficient to generate an overall negative investment response to uncertainty. However, each deviation leads to a different magnitude of the underlying overall derivative reflecting the differential impact of each factor. Higher market power alone reduces the overall derivative size from 0.43 to 0.07, while decreasing returns reduce the overall derivative size to 0.11. Formally testing for the equality of these derivatives indicates that high market power or decreasing returnsto-scale produce the same reduction, *i.e.* bring about quantitatively similar effects. This finding is clearly theoretically backed up by Caballero's (1991) seminal paper. Finally, irreversibility reduces the derivative from 0.43 to 0.35, which implies that this factor has the smallest impact. In addition, we emphatically reject the hypothesis that the irreversibility coefficient is of equal size to the other two coefficients (market power, returns-to-scale), in favour of the alternative that it is significantly smaller.

The next natural step is to 'increase' the degree of deviation from the Hartman-Abel benchmark, by considering the joint effect of two deviations at a time. There are a few important findings emerging from this exercise. In general, paired deviations exhibit sufficient thrust to convert, not only the magnitude, but also the sign of the investment-uncertainty relationship. As it is expected, the previously inferred ordering of individual effects is reflected in the properties of the paired effects. In particular, the largest negative investment response is generated when imperfect competition and decreasing returns are active (-0.25). Again as expected, whenever irreversibility is in operation jointly with another factor it results in a diluted effect. For instance, jointly considering irreversibility and decreasing returns, substantially reduces the derivative (from 0.43 to 0.03), although it remains in statistical terms significantly positive. In contrast, the joint effect of market power and irreversibility turns out to be marginally negative, nevertheless insignificantly different from zero. Finally, in the most severe set of deviations from the benchmark, corresponding to the case where all three dummies assume a value of unity, the derivative of investment is -0.33, and significantly negative. A very intuitive pictorial representation depicting how the investment sensitivity to uncertainty evolves across different environments is provided in the graph below.

[Graph]

Inspecting the graph, one may conclude that the magnitude and sign of investment's sensitivity to uncertainty change dramatically across alternative economic environments, as defined by different combinations of irreversibility, market power, and returns-to-scale. In general, as the severity of deviations from the benchmark progresses, investment elasticity eventually crosses the zero line and attains negative values. In terms of sign, one may discern three facets of this function: a) investment responding positively to uncertainty, when the environment is described by the Hartman-Abel setup, or when single-sourced deviations are in operation, or when irreversibility and decreasing returns are present,

b) zero sensitivity of investment, when high market power and irreversibility are jointly present. Note that the middle segment corresponding to the zero sensitivity implies the existence of an inflection point identifying a set of deviations severe enough to bring down the investment sensitivity from positive to zero,

c) investment exhibiting negative sensitivity to uncertainty, when either high market power and decreasing returns are in operation, or when all three deviations from the benchmark are operative.

6. Conclusions

In the present study we construct an empirical model that jointly accounts for all factors affecting the sign of the investment-uncertainty relationship augmented by an error correction mechanism. Sector-specific uncertainty is proxied by the conditional volatility of Net Operating Profits estimated by a Pooled Panel GARCH model. According to our results, the magnitude and sign of investment's sensitivity to uncertainty depend heavily on the assumptions regarding the profile of the economic environment, in terms of irreversibility, market power, and returns-to-scale. In general, as the severity of deviations from the benchmark progresses, investment elasticity eventually crosses the zero line and attains negative values.

Future research should focus on using alternative measures of irreversibility and/or more flexible production function specifications. Furthermore, a fruitful extension would be the distinction between systemic and idiosyncratic uncertainty.

Tables

Regressor	Estimates (z-scores)	
Constant	0.02*** (21.88)	
$\pi_{i,t-1}$	0.57 ^{***} (55.30)	
$\pi_{i,t-2}$	0.23 ^{***} (20.27)	
Conditional Variance Equation		
Constant	0.003 ^{***} (40.53)	
$\sigma_{i,t-1}^2$	0.51 ^{***} (22.29)	
$\sigma_{_{i,t-2}}^2$	0.46 ^{***} (24.77)	
Log-likelihood	2905.227	
Observations	3360	

Table 1 PP-GARCH model for Net Operation Profits

<u>Notes</u>: Numbers in parentheses denote z-scores. One, two, three asterisks denote significance at the 10, 5, and 1 percent level respectively.

Regressor	Estimates	
	(z-scores)	
$\left(\sigma ight)_{_{i,t}}$	0.43***	
	(10.41)	
$(\sigma * MP)_{i,t}$	-0.36***	
	(-9.43)	
$(\sigma * IRR)_{i,t}$	-0.08^{***}	
	(-2.68)	
$(\sigma * RS)_{_{i,t}}$	-0.32***	
	(-15.04)	
$(ECM)_{i,t-2}$	-0.05^{***}	
	(-38.88)	
$\left(\frac{l}{\kappa}\right)$	0.33***	
	(120.92)	
	(12002)	
$A \log(S)$	0.04***	
$\Delta \log \left(\frac{1}{K}\right)_{i,t}$	(68.02)	
(CF)	0.15***	
	(82.42)	
(K) _{i,t}	(02.42)	
Time Dummies	Included	
Observations	2210	
Diagnostics		
m_1	-8.06***	
<i>m</i> ₂	0.52	
Sargan	237.35	

 Table 2 Investment-Uncertainty Model

<u>Notes</u>: Numbers in parentheses denote z-scores, m_1 and m_2 are residual first and second order serial correlation tests, while Sargan stands for the over-identifying restrictions test. One, two, three asterisks denote significance at the 10, 5, and 1 percent level respectively.

Itoting					
Panel A					
Sources of Deviation from Benchmark	Coefficient Sum	Hypotheses Testing	Wald Test		
None (Benchmark)	0.43	$H_0: \delta_{unc} = 0$	$x^2 = 108.37^{***}$ (0.00)		
Irreversibility	0.35	$H_0: \delta_{irr} + \delta_{unc} = 0$	$x^2 = 257.13^{***}$ (0.00)		
Decreasing Returns	0.11	$H_0: \delta_{rs} + \delta_{unc} = 0$	$x^2 = 12.45^{***}$ (0.00)		
Market Power	0.07	$H_0: \delta_{mp} + \delta_{unc} = 0$	$x^2 = 12.98^{***}$ (0.00)		
Irreversibility and Decreasing Returns	0.03	$H_0: \delta_{irr} + \delta_{rs} + \delta_{unc} = 0$	$\begin{array}{c} x^2 = 351.82^{***} \\ (0.00) \end{array}$		
Market Power and Irreversibility	-0.01	$H_0: \delta_{mp} + \delta_{irr} + \delta_{unc} = 0$	$x^2 = 0.18$ (0.66)		
Market Power and Decreasing Returns	-0.25	$H_0: \delta_{mp} + \delta_{rs} + \delta_{unc} = 0$	$\begin{array}{c} x^2 = 205.35^{***} \\ (0.00) \end{array}$		
Market Power, Irreversibility, and Decreasing Returns	-0.33	$H_0: \delta_{mp} + \delta_{irr} + \delta_{rs} + \delta_{unc} = 0$	$x^2 = 76.18^{***}$ (0.00)		
Panel B					
Equal Impact	Coefficient Difference	Hypotheses Testing	Wald Test		
Market Power=Irreversibility	0.28	$H_0: \left \delta_{mp} \right = \left \delta_{irr} \right $	$\begin{array}{c} x^2 = 245.73^{***} \\ (0.00) \end{array}$		
Decreasing Returns=Irreversibility	0.24	$\overline{H_0: \left \delta_{rs} \right = \left \delta_{irr} \right }$	$x^2 = 48.71^{***}$ (0.00)		
Market Power=Decreasing Returns	0.04	$\overline{H_0:}\left \delta_{mp}\right =\left \delta_{rs}\right $	$x^2 = 1.34$ (0.24)		

 Table 3 Mapping the Investment-Uncertainty Relationship and Hypotheses

 Testing

Notes: In column 4 numbers in parentheses denote p-values; one, two, three asterisks denote significance at the 10, 5, and 1 percent level respectively.

Graphs



Mapping the Investment-Uncertainty Relationship

Notes: On the vertical axis we measure the value of estimated coefficients corresponding to different assumptions regarding the economic environment. The horizontal axis depicts the set of alternative economic environments. A stands for the Hartman-Abel benchmark, A/IRR is the benchmark allowing for irreversibility, A/RS is the benchmark allowing for decreasing returns, A/MP is the benchmark allowing for high market power. The remaining denote paired deviations from the benchmark, while the last A/MP/IRR/RS considers all three deviations.

References

Abel, A., (1983). "Optimal Investment under Uncertainty", *American Economic Review*, 73(1), 228-233.

Abel, A., and O., Blanchard, (1986). "The Present Value of Profits and Cyclical Movements in Investments", *Econometrica*, 54, 249-274.

Abel, A., and J., Eberly, (1994). "A Unified Model of Investment under Uncertainty", *American Economic Review*, 84, 1369-1384.

Abel, A., and J., Eberly, (1995). "The Effects of Irreversibility and Uncertainty on Capital Accumulation", *National Bureau of Economic Research*, Working Paper No 5363.

Abel, A., and J., Eberly, (1996). "Optimal Investment with Costly Reversibility", *Review of Economic Studies*, 63, 581-594.

Abel, A., and J., Eberly, (1999). "The Effects of Irreversibility and Uncertainty on Capital Accumulation", *Journal of Monetary Economics*, 44, 339-378.

Abel, A., Dixit, A., Eberly, J., and R., Pindyck, (1996). "Options, the Value of Capital, and Investment", *Quarterly Journal of Economics*, 111(3), 753-777.

Akaike, H., (1969). "Fitting Autoregressions for Prediction", Annals of the Institute of Statistical Mathematics, 21, 243-247.

Arellano, M., and S., Bond, (1991). "Some Tests of Specification for Panel Data: Monte Carlo Evidence and an Application to Employment Equations", *Review of Economic Studies*, 58, 277-297.

Bond, S., Elston-Ann, J., Mairesse, J., and B., Mulkay, (2003). "Financial Factors and Investment in Belgium, France, Germany, and the United Kingdom: A Comparison Using Company Panel Data", *Review of Economics and Statistics*, 85(1), 153-165.

Caballero, R., (1991). "On the Sign of the Investment-Uncertainty Relationship", *American Economic Review*, 81(1), 279-288.

Caballero, R., and R., Pindyck, (1996). "Uncertainty, Investment and Industry Evolution", *International Economic Review*, 37(3), 641-662.

Cermeno, R., and K., Grier, (2005). "Conditional Heteroskedasticity and Cross-Sectional Dependence in Panel Data: An Empirical Study of Inflation Uncertainty in the G7 Countries", In: Contributions in Economic Analysis, Badi H., Baltagi, Ed., North-Holland, *forthcoming*.

Chirinko, R., and H., Schaller, (2002). "The Irreversibility Premium", *Carleton University*, Working Paper.

Dixit, A., and R., Pindyck, (1994). *Investment under Uncertainty*, Princeton University Press, Princeton, NJ.

Domowitz, I., Hubbard, G., and B., Petersen, (1987). "Oligopoly Supergames: Some Empirical Evidence on Prices and Margins", *Journal of Industrial Economics*, 4, 379-398.

Drakos, K., (2006). "A Note on Uncertainty and Investment across the Spectrum of Irreversibility", *Applied Economics Letters*, forthcoming 2006.

Driver, C., Temple, P., and G., Urga, (2003). "Contrasts between Classes of Assets in Fixed Investment Equations as a Way of Testing Real Option Theory", *University of Surrey*, Working Paper.

Eberly, J., (1997). "International Evidence on Investment and Fundamentals", *European Economic Review*, 41, 1055-1078.

Fazzari, S., Hubbard, R., and B., Petersen, (1988). "Financing Constraints and Corporate Investment", *Brookings Papers on Economic Activity*, 19, 141-195.

Ghosal, V., and P., Loungani, (1996). "Product Market Competition and the Impact of Price Uncertainty on Investment: Some Evidence from US Manufacturing Industries", *Journal of Industrial Economics*, 44(2), 217-228.

Goel, R., and R., Ram, (1999). "Variations in the Effect of Uncertainty on Different Types of Investment: An Empirical Investigation", *Australian Economic Papers*, 38, 481-492.

Goel, R., and R., Ram, (2001). "Irreversibility of R&D Investment and the Adverse Effect of Uncertainty: Evidence from the OECD Countries", *Economics Letters*, 71, 287-291.

Guiso, L., and G., Parigi, (1999). "Investment and Demand Uncertainty", *Quarterly Journal of Economics*, 114(1), 185-227.

Hartman, R., (1972). "The Effects of Price and Cost Uncertainty on Investment", *Journal of Economic Theory*, 5, 258-266.

Hartman, R., (1976). "Factor Demand with Output Price Uncertainty", *American Economic Review*, 66(4), 675-681.

Kessides, I., (1990). "Market Concentration, Contestability, and Sunk Costs", *Review of Economics and Statistics*, 72(4), 614-622.

Leahy, J., and T., Whited, (1996). "The Effect of Uncertainty on Investment: Some Stylized Facts", *Journal of Money, Credit and Banking*, 28 (1), 64-83.

Lee, J., and K., Shin, (2000). "The Role of a Variable Input in the Relationship between Investment and Uncertainty", *American Economic Review*, 90(3), 667-680.

McDonald, R., and D., Siegel, (1986). "The Value of Waiting to Invest", *Quarterly Journal of Economics*, 101(4), 707-727.

Oi, W., (1961). "The Desirability of Price Instability under Perfect Competition", *Econometrica*, 29, 58-64.

Pindyck, R., (1988). "Irreversible Investment, Capacity Choice, and the Value of the Firm", *American Economic Review*, 78(5), 969-985.

Sakellaris, P., (1994). "A Note on Competitive Investment under Uncertainty; Comment", *American Economic Review*, 84(4), 1107-1112.

Sargan, J., (1958). "The Estimation of Economic Relationships using Instrumental Variables", *Econometrica*, 26, 393-415.

Worthington, P., (1995). "Investment, Cash Flow, and Sunk Costs", *Journal of Industrial Economics*, 43(1), 49-61.

Endnotes

¹ In the econometric analysis that will follow we abstain from considering attitudes towards risk due to the apparent difficulties in measurement. Essentially, we proceed by assuming that decisions makers are risk-neutral.

² 211; Extraction of metalliferous ores and preliminary processing of metal, 212; Extraction of nonmetalliferous ores and manufacture of non-metallic mineral products, 213; Chemicals and man-made fibres, 221; Manufacture of metal articles, Mechanical and instrument engineering, 222; Electrical and electronic equipment including office and computing equipment, 223; Manufacture of transport equipment, 231; Food, drink and tobacco, 232; Textiles, leather and clothing, 233; Timber and paper manufacture, printing, and 234; Other manufacturing industries not elsewhere specified.

³ There are 330 decision units, each sector includes 33 decision units (3 size classes from 11 countries), there are 10 sectors as defined above, and the time span is 16 years. This provides us with a total of 5280 (33*10*16) observations.