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Discovering the Link between Uncertainty and Investment — Microeconometric Evidence from Germany

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Abstract

We analyse empirically the effect of uncertainty on the investment decisions of a sample of quoted German firms. The uncertainty measures are constructed by employing two procedures: the conventional formula of standard deviation, and the GARCH methodology. We find that uncertainty exerts a significantly negative effect on investment, i.e. uncertainty slows down capital accumulation. We also find that this negative relationship is closely related to the degree of market power of the firm.

Keywords: Investment, Uncertainty, Irreversibility, Option Values, Panel Data
JEL Classification: C33, C61, D81, D92, E22

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"Where the stimulus to investment is concerned, the system is somewhat in the lap of the gods. We may be lucky or unlucky; and one of the few things you can say about luck is, 'It's going to change' "

P.A. Samuelson (1973) *Economics*, Ninth Edition, New York (McGraw-Hill), p. 208.

1 Introduction

It is often asserted that increasing uncertainty about future demand and/or profits reduces the incentive to invest. Although a statement of this kind is quite popular among business economists, it is not unanimously supported by academic economists. Many academic economists have tackled this important problem of capital investment spending under uncertainty but so far there exists no consensus as to the sign of the uncertainty-investment relationship. In the rather older literature, Hartman (1972) and Abel (1983) have demonstrated that a positive relationship should exist between output price uncertainty and investment for a competitive firm with constant returns to scale technology. This hypothesis crucially depends on the convexity of the marginal revenue product of capital in output price. On the contrary, the investment literature stressing irreversibility has developed since the late 1980s furnished with powerful mathematical tools exported from financial economics.[1] Irreversibility implies that investment goods specific to the firm may have little value to other firms, so that resale prices may be substantially below replacement costs, i.e. investment expenditures are sunk. By applying the option pricing approach it can be shown that in the presence of irreversibility under uncertainty there exist non-negligible opportunity costs of investing today rather than keeping the option of waiting to invest until new information arrives. The resulting investment strategy of the firm is to invest in a project only if the present value of expected cash flow exceeds the total cost including the value of waiting, i.e. the option theory to real investment invalidates the traditional net present value rule of investment. According to this burgeoning literature, a negative relationship between uncertainty and investment spending is more likely when the marginal revenue product of capital is decreasing in capital due to either imperfect competition or to decreasing returns in production (or both). The logic is that increasing uncertainty raises the probability that profits hit the investment threshold including the value of waiting to invest.

A quick glance at the theoretical literature indicates that the relationship between uncertainty and investment will only be settled after solid empirical evidence is obtained. The empirical literature, however, is lagging behind because of the difficulty of turning a theoretical innovation which essentially suggests that there is a greater range of inactivity before investment spending may be triggered, into an empirical model of investment spending. This study attempts to present microeconometric evidence for Germany.[2] The reason is that there are various studies investigating how uncertainty

[1]See the book by Dixit & Pindyck (1994).

[2]Other papers have analysed the impact of uncertainty upon investment behaviour using aggregate data [compare, for example, Ferderer (1993) and Serven (1998)]. This approach is, however, problem-

affects corporate investment behaviour in the U.S. and other European countries, but very few studies have been conducted for Germany.

The layout of the paper is as follows. In Section 2 we present models of firm investment decisions. Data, estimation issues and results are presented in the third section. The paper concludes with a brief discussion of policy issues relating to our results.

2 Models of Investment and Uncertainty

In a partial equilibrium model of production and investment, a firm is defined by production and demand functions and by the form of the stochastic processes it takes as given.[3] We consider a firm which faces an isoelastic demand function:

$$p(t) := Y(t)^{(1-\psi)/\psi} X(t) \qquad \psi \geq 1 \tag{1}$$

where p and Y respectively denote the price and the quantity of the good sold. ψ is an elasticity parameter that takes its minimum value of 1 under perfect competition. The stochastic term X evolves according to a geometric Brownian motion

$$dX = \mu X dt + \sigma X dz \tag{2}$$

where dz is the increment of a standard Wiener process, with $E[dz] = 0$ and $E[(dz)^2] = dt$. Alternatively, X can be characterized by the random walk process

$$X_t = X_{t-1} \exp \varepsilon \tag{3}$$

where ε is distributed normally with mean $\mu - \sigma^2/2$ and variance σ^2.[4] Every investment decision is taken at the beginning of each period, thus outcome is unknown since the future value of demand is always uncertain. The production technology is described by the Cobb-Douglas production function

$$Y = (AL^{\alpha} K^{1-\alpha})^{\gamma} \tag{4}$$

where L, K, and A are labour, capital, and the technology parameter at time t, respectively. The parameters α and γ are the constant labour share and an index of returns to scale, respectively. To keep the model simple we abstract from taxes. Since labour is assumed to be adjustable costlessly, the profit identity equation can then be specified as

$$\begin{aligned} \Pi &= max\{pY - wL\} \\ &= max\{(AL^{\alpha} K^{1-\alpha})^{\gamma/\psi} X - wL\} \end{aligned}$$

atic because most shocks are idiosyncratic to the firm. The question then arises whether aggregate studies can capture the uncertainty relevant to firm's investment decisions since idiosyncratic shocks tend to wash out in the aggregation process.

[3] For the sake of simplicity, we assume that there are no capital market imperfections and no heterogeneity across firms. Thus we abstract from some important issues that arise because we wish to focus on the uncertainty-investment link.

[4] On the contrary, certainty about the dynamic path followed by exogenous processes has been assumed in Hayashi (1982), or uncertainty is given in a form yielding certainty equivalence [for example, in Sargent (1979)].

It is convenient to define the common effect of the returns to scale and the competition parameter as $\xi := \gamma/\psi$. Maximizing profits yields

$$\Pi = hX^{\eta_x}K^{\eta_k} \tag{5}$$

where

$$\eta_x := \frac{1}{1-\alpha\xi} > 1, \qquad \eta_k := \frac{(1-\alpha)\xi}{1-\alpha\xi} \leq 1,$$

and

$$h := (1-\alpha\xi)\left(\frac{\alpha\xi}{w}\right)^{\frac{\alpha\xi}{1-\alpha\xi}} A^{\frac{\xi}{1-\alpha\xi}} > 0.$$

The capital accumulation constraint is given by

$$dK = (I - \delta K)dt \tag{6}$$

or

$$K_j = K_{j-1}(1-\delta) + I_j \tag{7}$$

in the discrete case. The costs of changing the stock of capital, $C(I)$, consist of three parts: fixed costs, the price of capital and the internal adjustment costs.[5]

1. Fixed costs of investment occur whenever investment is nonzero. They are constant, nonnegative and independent of the amount of investment.
2. Let b_1 and b_2 respectively be the price per unit of capital to be purchased and sold. We assume $b_1 \geq b_2 \geq 0$.
3. The adjustment costs of investment are typically assumed to be strictly convex and can therefore be written as a multiple of $|I|^\beta$ with $\beta > 0$.

$$C(I) = \begin{cases} a + b_1 I + \gamma_1 |I|^\beta & \text{if } I > 0 \\ 0 & \text{if } I = 0 \\ a + b_2 I + \gamma_2 |I|^\beta & \text{if } I < 0 \end{cases} \tag{8}$$

with $\gamma_1, \gamma_2 \geq 0$.

Last, the firm discounts expected future cash flows at a constant rate $r > 0$. We assume r to be large enough to ensure finite solutions of our problems. These formulas allow us to set up the continuous optimization problem.

[5] Abel & Eberly (1994) have introduced the fixed costs of capital and irreversibility (the difference between the purchase price and the resale price of capital) into the traditional adjustment cost function.

2.1 The Optimization Problem

The representative firm maximizes its expected fundamental value V, depending upon the actual capital stock K_0 and the stochastic variable X_0 under risk neutrality over an infinite horizon.[6]

$$V(K_0, X_0) = \max_I \int_0^\infty E\left[hX(\tau)^{\eta_x} K(\tau)^{\eta_k} - C\Big(I(\tau)\Big)\right] e^{-r\tau}\, d\tau \tag{9}$$

This present value satisfies the following Bellman equation:

$$rV(K_0, X_0) = \max_I \left\{ hX(t)^{\eta_x} K(t)^{\eta_k} - C\Big(I(t)\Big) + \frac{E[dV]}{dt} \right\} \tag{10}$$

The equation requires that the return rV equals the sum of the actual cash flow $hX^{\eta_x}K^{\eta_k} - C(I)$ and the expected capital gain $\frac{E[dV]}{dt}$. The next step is to resolve the expectation $E[dV]/dt$ applying Itos lemma.

$$rV = \max_I \left\{ hX^{\eta_x}K^{\eta_k} - C(I) + (I - \delta K_0)\frac{\partial V}{\partial K} + \mu X \frac{\partial V}{\partial X} + \frac{1}{2}\sigma^2 X^2 \frac{\partial^2 V}{\partial X^2} \right\} \tag{11}$$

Now define $q := \frac{\partial V}{\partial K}$ the marginal valuation of a unit of installed capital.[7] Then optimal investment solves the term

$$\max\{-C(I) + Iq\}$$

Via the first order conditions

$$-b_1 - \beta\gamma_1 |I|^{\beta-1} + q \stackrel{!}{=} 0 \qquad \text{or} \qquad -b_2 - \beta\gamma_2 |I|^{\beta-1} + q \stackrel{!}{=} 0 \tag{12}$$

it is a simple matter to get

$$I_1 = \left|\frac{q - b_1}{\beta\gamma_1}\right|^{1/(\beta-1)} \qquad \text{and} \qquad I_2 = -\left|\frac{q - b_2}{\beta\gamma_2}\right|^{1/(\beta-1)} \tag{13}$$

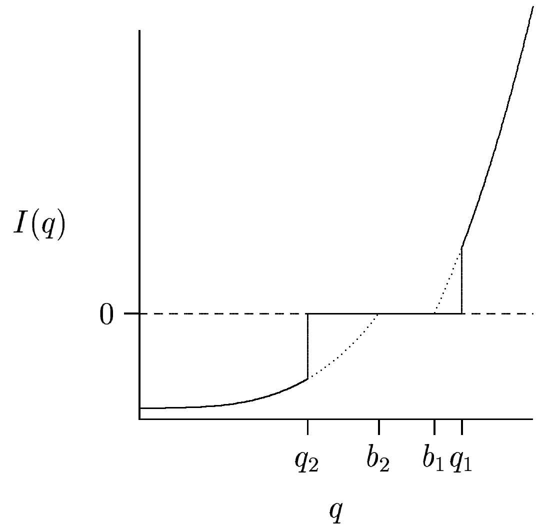
Since the term $-C(I) + Iq$ is zero for zero investment, $I_{1/2}$ is only optimal if $-C(I_{1/2}) + I_{1/2}q \geq 0$. Therefore we define q_1 and q_2 as the unique roots of $-C(I_1) + I_1 q = 0$ and $-C(I_2) + I_2 q = 0$, respectively.

$$q_1 := b_1 + (a/\Gamma_1)^{(\beta-1)/\beta} \quad \text{and } q_2 := b_2 - (a/\Gamma_2)^{(\beta-1)/\beta}$$

[6] The continuous optimization problem is drawn up in detail in Abel & Eberly (1994).

[7] Hayashi (1982) has provided conditions justifying the use of average q (qA) instead of marginal q in empirical work. These conditions are that the firm is a price-taker, its production function is linearly homogeneous in its inputs, and the adjustment cost function is linearly homogeneous in I and K. Abel & Eberly (1994) show that if instead the profit function and the adjustment cost function are homogeneous of degree γ, the two measures of q are proportional and $q = \gamma qA$.

Figure 1: The Relationship Between Investment and the Marginal Valuation of Capital



with $\Gamma_i := \frac{\gamma_i(\beta-1)}{(\gamma_i\beta)^{\beta/(\beta-1)}}$. The optimal investment schedule is then characterized by

$$I^* = \begin{cases} I_1 & \text{if } q > q_1 \\ 0 & \text{if } q_2 \leq q \leq q_1 \\ I_2 & \text{if } q < q_2 \end{cases} \tag{14}$$

Figure 1 illustrates this result. There are three regimes for investment; if $q < q_2$, gross investment is negative; if $q_2 \leq q \leq q_1$, investment is zero and finally, if $q > q_1$, then investment is positive and increasing in q.[8] In other words, there exists an interval that is determined by the trigger values of q in which the sensitivity of investment to q is zero. This result allows us to understand why the investment curve appears so unstable, and why sometimes the decisions of firms and investors are so sensitive to the expected future pattern of the economic activity. Note, in the regions where investment does respond to q, the relationship need not necessarily be linear.[9]

2.2 Perfect Competition and Constant Returns to Scale

In the special case of perfect competition and constant returns to scale we can be derive some further insights. We demontrate the positive investment uncertainty relationship for this case.

[8] Empirical evidence of the nonlinearity between investment and Tobin's q are given in Eberly (1997) and Barnett & Sakellaris (1998).

[9] One intuition for this nonlinear and non-continuous investment function is straightforward. The expected sequence of future profits is relevant for a forward looking firm. Suppose, there are two states - high profits and low profits - both of which are persistent. Suppose further that the economy has been in the low profit regime for some time and the firm is thus quite confident about the true regime. A shift to a high-profit-regime implies that investment should increase. The firm, however, may not react immediately, because it must disentangle the regime shift from transitory shocks, and because its prior belief is that the low profit state will persist. This may cause substantial sluggishness. For a model in which such learning plays a role, see Demers (1991).

The competition parameter ψ and the index of returns to scale γ determine together the variable ξ. In the case of perfect competition and constant returns to scale ψ takes its minimum value 1 and γ takes its maximum value 1 and therefore $\xi = 1$. Thus the differential equation (11) becomes linear in K. Furthermore one can show (Abel & Eberly (1994)) that the value function $V(K, X)$, too, becomes linear. This linearity enables some further analytical results. The results for the continuous maximizing problem are well discussed in Abel & Eberly (1997). With the linear hypothesis $V = qK + G$, we can divide equation (11) to two ordinary differential equations by separating terms which include the capital stock K or not.

$$rq(X) = hX^{\eta_x} - \delta q(X) + \mu X q'(X) + \frac{\sigma^2}{2} X^2 q''(X) \tag{15}$$

and

$$rG(X) = (q(X) - b_i)^{\frac{\beta}{\beta-1}} \Gamma_i - a_{I \neq 0} + \mu X G'(X) + \frac{\sigma^2}{2} X^2 G''(X), \quad i = 1, 2 \tag{16}$$

where $\Gamma_i := \dfrac{\gamma_i(\beta - 1)}{(\beta\gamma)^{\frac{\beta}{\beta-1}}}$.

From equation (15) we get the marginal valuation of capital

$$q = \frac{hX^{\eta_x}}{f(\eta_x, r + \delta)} + c_1 X^{\zeta_1} + c_2 X^{\zeta_2} \tag{17}$$

where $f(\lambda, \rho) := \rho - \lambda\mu - \frac{1}{2}\sigma^2\lambda(\lambda - 1)$ and $\zeta_{1/2} := \frac{-2\mu+\sigma^2 \pm \sqrt{8(r+\delta)\sigma^2 + (2\mu-\sigma^2)^2}}{2\sigma^2}$ are the roots of of $f(\zeta, r + \delta) = 0$. With the boundary condition $q(X = 0) < \infty$ and the transversality condition $\int_0^\infty q_t e^{-t(r+\delta)} dt < \infty$ we have $c_1 = c_2 = 0$. Note that q does not depend on the parameters of the investment cost function. Since investment depends only on q and not on G (see equation 13) we will consider directly the investment uncertainty-relationship: We can evaluate

$$\begin{aligned} \frac{dI}{d\sigma} &= \frac{dI}{dq} \cdot \frac{dq}{d\sigma} \\ &= \frac{\text{sign } I}{(\beta - 1)(q - b_i)} \left| \frac{q - b_i}{\beta\gamma_1} \right|^{1/(\beta-1)} \cdot \frac{hX^{\eta_x}(\eta_x - 1)\eta_x \sigma}{f(\eta_x, r + \delta)^2} \\ &> 0 \end{aligned} \tag{18}$$

if investment is reversible. In the case of irreversibility, equation (18) holds if $q > b_1$ and $dI/d\sigma = 0$ if $q \leq b_1$. In other words in the case of perfect competition and constant returns to scale investment expenditures increase with uncertainty (mean preserving spread). Any asymmetries in the adjustment costs ($\gamma_1 \neq \gamma_2$) influence the shape of the investment-uncertainty relationship but not its sign.

2.3 Numerical Results

In the general case there are no closed-form solutions of the investment model. For further insights it is therefore necessary to solve the model numerically.[10] We use the discrete form of the model with two periods.

$$V_j(K_{j-1}, X_j) = \max_{I_J} \left\{ \Pi(K_j, X_j) - C(I_j) + \frac{1}{1+r} E_j[V_{j+1}(K_j, X_{j+1})] \right\} \tag{19}$$

and

$$V_{N+1} = 0$$

The firm starts the first period with a capital stock of $K_0 = 100$ and the random variable X_0 is set to an equilibrium value, so that optimal investment without uncertainty equals depreciation $I_{0,\sigma=0} = \delta K_0 = 10$.[11]

Figure 2: Investment as a Function of Uncertainty for Different Values of ξ

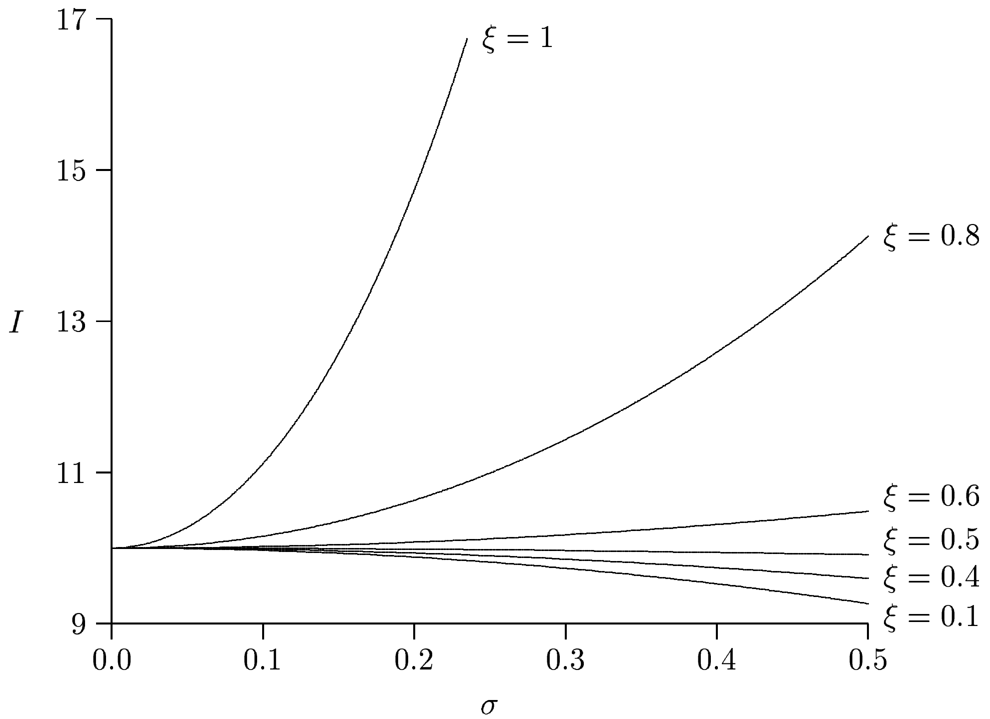
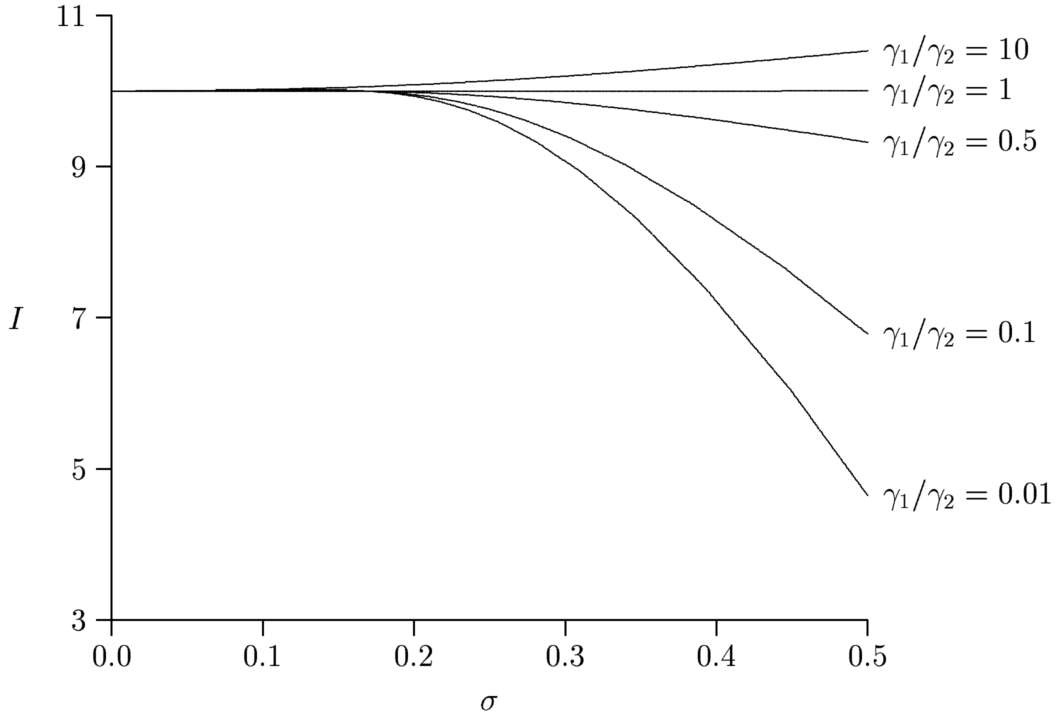


Figure 2 illustrates that with imperfect competition the uncertainty-investment relationship turns out to be negative. This result confirms Caballero's (1991) result that the existence of imperfect competition is a necessary condition for the irreversibility-

[10] Caballero (1991) has produced his numerical simulations with several simplifications of the model; this is, however, no longer necessary with up-to-date PCs and workstations.

[11] Our base choice of parameters is $a_0 = 0$, $b_1 = 1$, $b_2 = 1$, $\gamma_1 = 0.01$, $\gamma_2 = 0.01$, $\beta = 2.00$, $\xi = 0.52$, $\alpha = 0.7$, $w = 0.7$, $A = 1$, $r = 0.02$, $\delta = 0.1$, $\mu = 0$. γ_1, ξ and b_2 are set to other values if explicitly specified. All computations in the paper have been produced using C.

Figure 3: Investment as a Function of Uncertainty for Different Values of γ_1/γ_2



driven negative relationship between investment and σ.[12]

Figure 3 plots investment as a function of uncertainty for various asymmetric adjustment cost parameters.[13] For $\gamma_1/\gamma_2 < 1$, adjustment costs of disinvestment are larger than for investment. The intuition for this result is straightforward. Since many productive facilities are firm-specific, markets for most used machinery are thin and discount is heavily, $\gamma_1/\gamma_2 < 1$ seems to be a reasonable assumption. The much larger investment restraint for $\gamma_1/\gamma_2 \ll 1$ in Figure 3 is not surprising: higher asymmetries worsen the "worst case" scenario, in which the firm regrets the irreversible investment decision. On the contrary, higher variance σ does not symmetrically improve the demand for investment for $\gamma_1/\gamma_2 \gg 1$. In other words, the irreversibility constraint binds much more in case of asymmetric adjustment costs and therefore truncates the (log-normal) probability distribution of future states of nature.[14]

[12] The important role of imperfect competition in determining the sign of the uncertainty-investment relationship has originally been developed by Smith (1969) in a static context without adjustment costs. Empirical evidence for this industrial organisation insight that the sign of the uncertainty-investment relationship depends upon market power is available in Ghosal & Loungani (1996) and Guiso & Parigi (1999).

[13] In a separate strand of literature, asymmetric adjustment costs have also been found in labour demand functions. Compare Pfann & Palm (1993), for example.

[14] Bernanke (1983) refers to this insight as the "bad news principle".

3 Data and Estimation

3.1 Measuring Uncertainty

It is clear that uncertainty can take many forms. It is therefore not surprising that a variety of measures for uncertainty has been devised in empirical studies to analyse the uncertainty-investment relationship. For example, Huizinga (1993) has constructed the conditional standard error of the residuals from an ARCH model, Guiso & Parigi (1999) have used survey data, while Ghosal & Loungani (1996) have applied the rolling regression technique to obtain a measure of uncertainty. We use two different statistical methods to construct uncertainty proxies. First, uncertainty measure U_1 is simply computed as the conventional standard error of daily stock returns for each year in the sample.[15] Second, we have used the GARCH technique to compute the conditional standard deviation of firm's daily stock returns. Specifically, we have estimated GARCH(1,1) models for the firm's daily stock returns.[16] In this manner the uncertainty measure U_2 is given by the average conditional standard deviation for each year in the sample.[17] Table 1 shows the summary statistics of both uncertainty measures constructed. It gives the sample means across firms for each year.

Table 1: Yearly Sample Means of the Uncertainty Measures across Firms

Year	Uncertainty Measure U_1	Uncertainty Measure U_2
1987	0.0209	0.0190
1988	0.0165	0.0168
1989	0.0184	0.0175
1990	0.0184	0.0190
1991	0.0184	0.0184
1992	0.0171	0.0173
1993	0.0189	0.0185
1994	0.0231	0.0221
Total Avg.	0.0190	0.0186

It is found that on the whole both uncertainty measures are similar in magnitude. We observe a slightly declining trend from 1987 to 1992 until it started to rise again in 1993. Finally, we have also computed the sample correlation coefficients between both uncertainty measures. The correlation coefficient between the uncertainty measure based on the GARCH(1,1) model and that based on the conventional standard

[15]The a priori choice of the share price growth rate is justified by the underlying q-type investment function.

[16]Note that the information set available for the firm under the GARCH-type measure is different from the first approach since in the U_2 measure we utilize the full information set including the future information to obtain the conditional standard deviation of the current year. On the contrary, the uncertainty measure U_1 for a certain year is purely based on the information set within that year. In other words, we mimic the information structure of the firms facing the current investment decision.

[17]Leahy & Whited (1996) have emphasized that uncertainty relates to expectations and not to actual outcomes. It might therefore be incorrect to use ex post measures of uncertainty and therefore they propose a way to construct forecasts of volatility using a VAR technique. Unfortunately, GARCH models provide seemingly poor volatility forecasts [see, e.g., Cumby, Figlewski & Hasbrouck (1993) and Jogion (1995) among many others] and therefore we will not use ex ante measures of uncertainty in this paper.

deviation formula is 0.85. The cross-sectional distributions of the uncertainty measures across firms will also be informative. Figure 4 and 5 show the frequency distribution of the uncertainty measures across firms for the beginning and the end of the sample period (1987 and 1994). The frequency distributions are skewed to the right in both years.

Figure 4: Frequency Distribution of Uncertainty Measures U_1 and U_2 in 1987 (U_1 shaded, U_2 dotted)

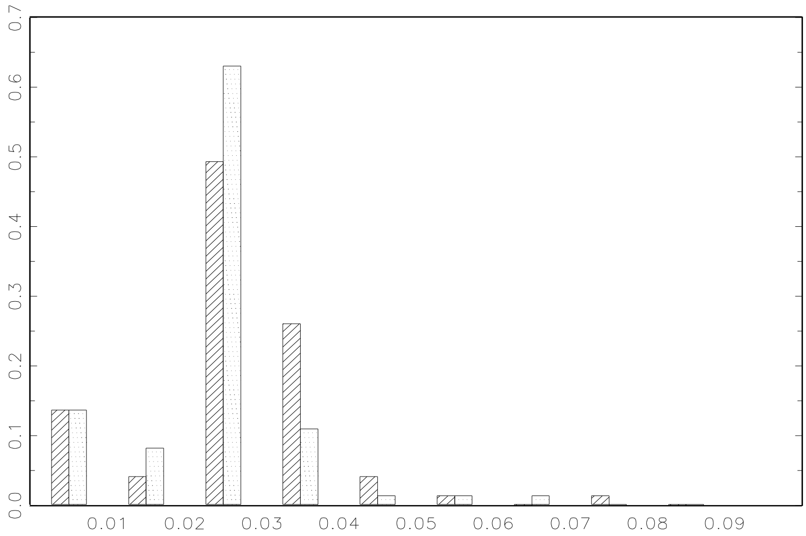
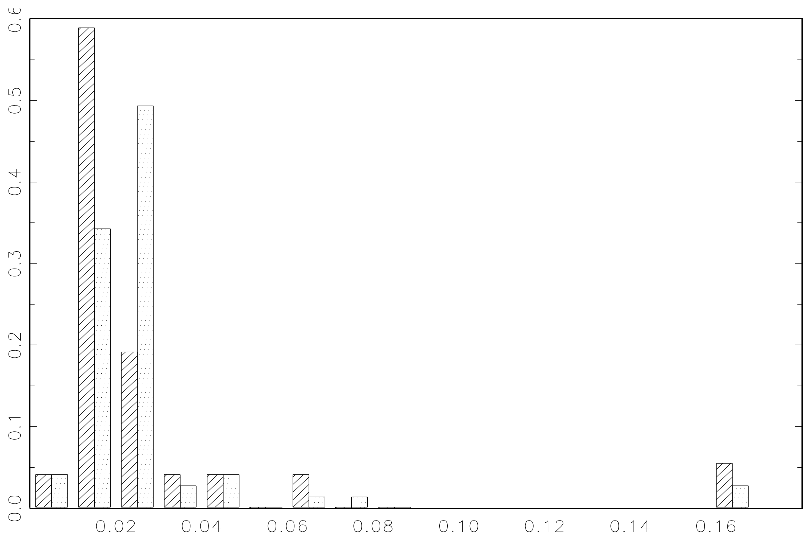


Figure 5: Frequency Distribution of Uncertainty Measures U_1 and U_2 in 1994 (U_1 shaded, U_2 dotted)



3.2 Company Data Set

The investment equations are estimated on the basis of panel data of quoted German firms listed on the Frankfurt stock exchange. We first describe the dataset to be used, followed by the discussion of the uncertainty measures used and the econometric method employed for estimation. The unbalanced panel contains 70 quoted firms and covers the years from 1987 to 1994.[18] Most of the sample firms belong to manufacturing industries and they are chosen out of the largest 100 German firms on the criterion that there have been no large mergers and acquisitions during the sample period.[19] More detailed information on the sample firms is shown in Table 2 and a detailed description of the various variables is given in the appendix.

Table 2: Panel Structure

Number of Firms	Number of consecutive years available for estimation
3	5
4	6
7	7
56	8
Total: 536 observations covering 70 firms	

Table 3: Descriptive Statistics

Variable	Symbol	Min.	Max.	Mean	Standard Deviation
Investment-Rate	$I/K(t)$	-5.258	4.437	0.467	0.522
Tobin's Q	$Q(t)$	1.097	30.926	4.054	2.876
	$U_1(t)$	0	12.011	1.463	1.482
	$U_1(t) * MS$	0	616.661	43.887	67.954
	$U_2(t)$	0	16.131	1.447	1.403
	$U_2(t) * MS$	0	828.187	42.961	62.276

3.3 Panel Data Estimation Issues and Results

To estimate dynamic factor demand equations using a panel data set containing many firms and a moderately small number of time periods, we use the *system* generalized method of moments (GMM) estimator developed by Blundell & Bond (1998).[20] This is an efficient extension of the Arellano & Bond (1991) *first-difference* GMM estimator which can be subject to a large downward bias and very low precision as a result of weak instruments in situations where the series are highly persistent and/or the relative variance of the fixed effects increases even for large N when T is small. The *system* GMM estimator combines the first-difference and the level specification deal with the

[18] The dataset starts in 1987 because in 1986/1987 large changes in the terms for settlements of consolidated accounts have occurred.

[19] The size of firms was measured by the variable 'sales'.

[20] It is outside the scope of this paper to give a detailed overview on dynamic panel data estimation issues. The growing interest in panel data modelling reflects the increasing availability of such data and enormous advances in computing technology. The interested reader is referred to Baltagi (1995), 125-144, Arellano & Bover (1995), Altonji & Segal (1996), Ahn & Schmidt (1995), Judson & Owen (1997), Kiviet (1995), Ziliak (1997) and Blundell & Bond (1998). The system GMM estimates and the specification tests that we report are computed using DPD98 written in GAUSS [see Arellano & Bond (1998)].

problem of "weak instruments" highlighted in recent empirical work.[21] The system GMM estimator uses equations in first-differences, from which the firm-specific effects are eliminated by the transformation, and for which endogenous variables lagged two or more periods will be valid instruments provided there is no serial correlation in the time-varying component of the error terms. Since the consistency of the estimator relies on this assumption, we report LM-test for the lack of first-order and second-order serial correlation in the residuals. If the residuals are serially uncorrelated, then the first differences transformation induces first-order serial correlation, but not second-order.[22] These differenced equations are then combined with equations in levels, for which the instruments used must be orthogonal to the firm-specific effects.[23] Obviously the level of the dependent variable is correlated with the firm-specific effect, and we also want to allow for the levels of the explanatory variables to be potentially correlated with the firm-specific effects. This rules out using the levels of any variables as instruments for the levels-equation. However, Blundell & Bond (1998) show that in autoregressive distributed lag models, first-differences of the series can be uncorrelated with the firm-specific effects provided that the series have stationary means. We therefore experimented with lagged-differences of the variables as instruments for the levels equation. In the estimates we essentially use lags of all the company level variables in the model. As a check for the validity of the selected instruments used, we present Sargan's test of over-identifying restrictions to ensure that the instruments are uncorrelated with the estimated residuals from the model. We report results for the one-step and the two-step GMM estimator, with t-values and test statistics that are asymptotically robust to general heteroscedasticity.

From the preceding theoretical discussion it is clear that irreversibility *per se* is not sufficient to turn around the positive impact of uncertainty on investment following from the convexity of the profit function. Indeed, even under asymmetric adjustment costs optimal investment by a competitive firm continues to be a non-decreasing function of uncertainty. To reverse this results it is necessary to bring in additional assumptions such as imperfect competition or decreasing returns to scale (or both). When combined with irreversibility, they can create a negative uncertainty-investment link by making the marginal revenue product of capital a decreasing function of the capital stock.[24] In order to address this ambiguity, we have added interactive terms between our uncertainty measures and proxies for the market structure as additional regressors to our Q-type investment function. In other words, the estimated equations allow the sign of the uncertainty-investment link to vary with the degree of market power.

[21] While it is often impossible to obtain strictly exogenous instruments, one can use predetermined instruments using lagged values of the right-hand side variables.

[22] See Arellano & Bond (1991), p. 281.

[23] Thus we exploit the additional linear moment restrictions (4.3) and (4.4) in Blundell & Bond (1998).

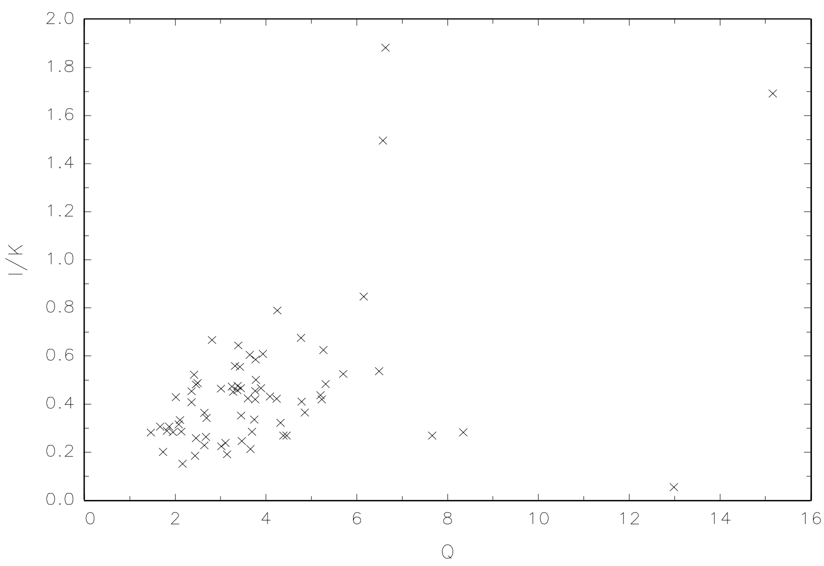
[24] The assumption that the marginal profitability of capital declines with the capital stock obviously cannot apply to a constant-returns perfectly competitive firm for which the marginal profitability of capital is, by construction, unrelated to the level of capital. It should be mentioned that the theoretical modelling exercise above has been limited to the risk-neutral case. An alternative approach takes as starting point the case of risk-averse agents facing limited diversification possibilities in the context of imperfect capital markets. Along these lines, Zeira (1990) presents a model of investment by perfectly competitive risk-averse investors facing uncertain prices. In this framework, uncertainty has an ambiguous impact on investment: on the one hand, it tends to raise investment through the convexity of the profit function; on the other hand, higher uncertainty discourages investment due to investors' risk aversion.

The GMM estimation results that correct for both endogeneity and unobserved country-specific effects are given in Table 4. We use a simple empirical specification of the form:

$$(I/K)_{it} = f\left((I/K)_{i,t-1}, \mathbf{x}_{it}\right) + \varepsilon_{it} \tag{20}$$

where I/K is the investment rate; $\mathbf{x}$ is a set of investment determinants, ε is a random disturbance and the subscripts $i = 1, \ldots, N$ and $t = 1, \ldots, T$ refer to the cross-section and time-series dimension of the data, respectively.[25] Among the $\mathbf{x}$ variables, we include Tobin's Q, the uncertainty measures U_1 and U_2, and the interaction terms (cross terms) between the uncertainty measure and our measure for market power (MS).[26] The regressions assume that all the explanatory variables are endogenous, and in consequence they are all instrumented. Because strictly exogenous instruments are in general hard to come by, we have used 'internal' predetermined instruments using lagged values of the right-hand side variables. The sample period for estimation is virtually from 1989 to 1994, since some observations are lost to instrument the variables.

Figure 6: Average I/K vs Q across firms



The estimated coefficients on the lagged dependent variable are about 0.25 and generally highly significant.[27] The size of the Q-coefficients is small but appears reasonable and significant.[28] We now turn to the interpretation of the estimated coefficients of the uncertainty terms. Interestingly, the uncertainty measure U_1 and U_2 have a small *positive* effect on investment, while the interaction variables ($U_1 \times MS$ and $U_2 \times MS$) enter the equations *negative*. This qualitative result turns out irrespective of the choice

[25]Obviously, the first difference estimator has the drawback that first-differencing removes the long-run (cross firm) information present in the levels of the variables.

[26]The variable MS has been calculated for 22 two-digit industries.

[27]We have reported White-corrected one-step and two-step t-statistics, since one has to keep in mind that the t-statistics of the two-step estimator are systematically too high. In a Monte Carlo study, Arellano & Bond (1991) quantify the downward bias of the two-step standard errors to be about 20%. Given that caveat, our estimated t-statistics seem still reasonable.

[28]A quick column-by-column comparison reveals very little difference concerning the size and the significance of the Q-coefficient for each of the specifications. It might be objected that we have generally assumed that investment responds to Q continuously although the underlying model allows for a S-shaped relationship due to the curvature of the cost function. The reason is that such a nonlinear response of investment to Q is not supported by the data (also compare figure 6).

Table 4: GMM Estimation Results

	(1)	(2)	(3)	(4)	(5)
$I/K(t-1)$	0.278	0.266	0.260	0.265	0.261
	(4.48)	(4.60)	(4.17)	(4.72)	(4.51)
	[15.12]	[16.48]	[18.49]	[16.75]	[20.01]
$Q(t)$	0.046	0.046	0.045	0.047	0.046
	(1.24)	(1.25)	(1.26)	(1.26)	(1.25)
	[15.85]	[20.46]	[21.70]	[20.13]	[25.93]
$U_1(t)$		0.022	0.082		
		(1.24)	(1.59)		
		[2.99]	[4.03]		
$U_1(t) * MS$			-0.002		
			(-1.42)		
			[-3.00]		
$U_2(t)$				0.018	0.064
				(1.07)	(1.21)
				[2.03]	[4.27]
$U_2(t) * MS$					-0.001
					(-1.11)
					[-3.35]
Wald-test,	352.34	605.41	649.60	554.85	868.03
Joint Signif.	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Wald-test,	22.27	40.34	68.80	47.26	68.25
Time-Dummies	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Wald-Test,			18.28		18.31
Uncertainty			(0.00)		(0.00)
Sargan	22.12	25.47	28.04	25.51	29.93
p-value	(0.14)	(0.33)	(0.57)	(0.33)	(0.47)
$AC(1)$	-1.725	-1.699	-1.687	-1.698	-1.689
$AC(2)$	-1.016	-1.005	-0.980	-1.011	-0.995

Notes: The upper part displays estimated coefficients with one-step [two step] t-values robust to heteroskedasticity in parentheses [in square brackets]. The lower part shows test results and diagnostics from two-step estimation with p-values in parentheses. *Wald-test* test for the significance of all coefficients, all time-dummies and both uncertainty terms, where applicable. *Sargan* tests the Null of instrument validity for the second step, and $AC(1)$ [$AC(2)$] test for first [second] order autocorrelation in the differenced residuals. The statistics are asymptotically distributed $N(0,1)$. If the residuals are i.i.d., we expect to find negative first order autocorrelation but no second-order autocorrelation.

of the uncertainty measure.[29] Finally, the diagnostics are generally satisfactory. In conclusion, the sign pattern underscores the robustness of the underlying theoretical investment-uncertainty link. As stated in the outset, uncertainty and irreversibility *per se* is not enough for deriving a negative relationship between uncertainty and investment activity. Imperfect competition in the output market is an important ingredient to generate a negative relationship.[30]

4 Concluding Remarks

It is not unusual that economic theory gives ambivalent verdict on a relationship among economic variables. This is exactly the case for the uncertainty-investment relationship. In this situation it is the task of empirical researchers to bridge the gap between theoretical models and economic reality. Our study has the very nature of this kind. Based upon the German panel data set, we have examined how the uncertainty proxies have affected firm level investment decisions over the period 1987 to 1994. The results support the conjecture that 'uncertainty' as defined in this paper, is associated with modified investment behaviour on the part of quoted German firms. We obtain a positive uncertainty-investment link and also find that there is considerable heterogeneity in the uncertainty-investment link across firms that differ in the degree of market power. Consistent with the simulation results in Figure 2, the impact of uncertainty upon capital accumulation turns out to be negative for firms operating in more concentrating industries.

[29]This results contradicts the empirical evidence for the U.S. in Leahy & Whited (1996). In their paper the coefficients of uncertainty turn out insignificant when they control for Tobin's Q implying that uncertainty affects investment mainly through Q.

[30]This result is in broad agreement with the results in Ghosal & Loungani (1996) and Guiso & Parigi (1999) for the U.S. and Italy, respectively.

A Data Descriptions

Data have been collected from business reports of German quoted firms. The definitions are as follows.

I	Gross investment, given by the change in fixed assets plus write offs.
K	Book value of fixed assets.
Q	Average q, calculated by the market value of equity plus the book value of debt divided by K at replacement costs.
U_1	The annual standard deviation of the daily stock price's growth rate.
U_2	The annual standard deviation of residuals from a GARCH(1,1) fitted to the daily stock price growth rate.
MS	A measure for the concentration of the market the respective firms acts in. We measure market structure as the share of the ten largest firms in the German market at the two-digit level. The 22 MS-measures have been calculated using the AMADEUS database covering about 10 000 German firms. The measures are available upon request.

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