Real versus Financial Frictions to Capital Investment[*]

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Abstract

We examine the investment behavior of a panel of German manufacturing firms for the time period from 1992 to 2000. Our methodology is structural and has several steps: First, we identify the profitability shocks that move investment demand at the firm level. Then, we specify an array of adjustment costs and capital market imperfections possibly influencing optimal firm investment response to these shocks. Finally, we use an indirect inference procedure as in Gourieroux, Monfort and Renault (1993) and Smith (1993) to estimate the structural parameters. Our goal is to characterize the relative importance of financing constraints and various costs of adjustment in German manufacturing.

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1 Introduction

Investment is an important component of aggregate activity and much e¤ort has been spent on trying to understand it. The workhorse of modern investment research has been Tobin's Q theory and the neoclassical theory of investment with convex adjustment costs.[1] In this framework, the market value of capital is an important determinant of a …rm's capital investment decision. It is fair to say that the initial empirical results of this research have been largely disappointing. Brie‡y, the estimates of investment responsiveness to fundamentals have been very low whereas output terms (such as pro…ts) have been very signi…cant contrary to theoretical implications. This has continuously set a challenge on empirical work.

The research of the last …fteen years has experienced two breakthroughs. In reverse chronological order, one emphasizes the importance of nonlinearities and the other of …nancing constraints. Below we review brie‡y these two in‡uential strands.

Nonlinearity

This literature argues that the apparent failures of neoclassical theory are a result of misspeci…cation of the costs that are relevant in the capital adjustment decision. In particular, irreversibilities and …xed costs to investment may lead …rms to experience episodes of zero investment as well as episodes of large investment in response to similarly small movements in fundamentals. This is in sharp contrast to convex adjustment costs which, at least in their usual quadratic implementation, imply proportional responses. This provides an explanation for the low estimated responsiveness in the data of investment to fundamentals.[2]

One of the …rst empirical contributions in this mold is Doms and Dunne (1998) who show that in a sample of U.S. manufacturing establishments about 25 percent of a typical establishment's total investment over 17 years is concentrated in a single year. Caballero, Engel and Haltiwanger (1995) and Caballero and Engel (1999) show that investment response to fundamentals, measured by the gap between actual and desired capital stock, is

[1] See Tobin (1969), Lucas and Prescott (1971), Mussa (1977), Hayashi(1982), Abel (1983) for seminal contributions as well as Abel (1990) for a review and link to Jorgenson's (1963) user cost concept.

[2] The role of irreversibilities was stressed by Dixit and Pindyck (1994), Bertola and Caballero (1994), and Abel and Eberly (1996), among others. The role of …xed costs was stressed by Abel and Eberly (1994), Caballero and Leahy (1996), and Caballero and Engel (1999), among others.

disproportionately larger for a larger gap. Cooper, Haltiwanger and Power (1999), Schiantarelli and Nilsen (1999) provide evidence that the hazard of a large investment "spike" is increasing in the years since the last investment "spike." Barnett and Sakellaris (1998), Barnett and Sakellaris (1999), and Abel and Eberly (2002a) …nd that investment responsiveness to Tobin's Q is highly non-linear. Finally, Ramey and Shapiro (2001) …nd that for some plants in the US aerospace industry the discounts on reselling capital assets average 25 percent. All this evidence is consistent with important non-convex adjustment costs. An in‡uential paper by Cooper and Haltiwanger (2002) provides structural estimates supporting the existence of both convex and …xed costs in plant-level investment activities in US manufacturing.

In summary, some lessons from this literature are that: 1) Tobin's Q is quite informative for investment once nonlinearity is allowed, and 2) it is not warranted to give structural adjustment cost interpretation to coe¢cients based on regressions of investment on Q.[3]

Financing constraints

Firms rely mainly on internal sources of funds to …nance investment.[4] This has been interpreted as evidence of a divergence between the costs of internal and external funds. Early theories leading to such a cost wedge or, even, rationing of external funds invoked the existence of information asymmetries or agency problems. The importance of internal funds in predicting aggregate investment has been recognized at least since Meyer and Kuh (1957). However, Fazzari, Hubbard and Petersen (1988) has been instrumental in connecting this observation to …nancial market imperfections and testing it at the …rm level. Their basic working hypothesis is that the sensitivity of investment to cash ‡ow should be higher for …rms that face a larger wedge in the cost of internal and external funds(monotonicity hypothesis). They argue they could identify *a priori* liquidity constrained …rms and then demonstrated for these a high sensitivity of investment to cash ‡ows. On the other hand, Tobin's Q appears to have only a marginal impact on investment for these …rms.[5] [6]

[3] Abel and Eberly (2002b, and c) provide some fresh models resulting in the second lesson above.

[4] Ross, Wester…eld and Jordan (1999) document that …rms raise more than 80 percent of equity from internal sources.

[5] A voluminous literature followed them in this approach including Hoshi, Kashyap, and Scharfstein (1991) for Japanese …rms. See Schiantarelli (1996) and Hubbard (1998) for a survey.

[6] A parallel literature has examined inventory investment behavior arguing for the importance of …nancing constraints in explaining the dramatic cycles in inventory investment. See Kashyap, Lamont and Stein (1994)

Kaplan and Zingales (1997), however, have questioned the validity of this approach for testing the existence of …nancing constraints. They argue that the monotonicity hypothesis is not a necessary prediction of a model of optimal investment under …nancial constraints. They also question several of the methods used in the literature to identify a priori liquidity constrained …rms.[7]

Other criticisms have arisen too. Gomes (2001) demonstrates that the existence of …nancing constraints is not su¢cient to establish cash ‡ow as a signi…cant regressor in standard investment regressions that include Q. Furthermore, …nancing constraints are not necessary to obtain signi…cant cash ‡ow coe¢cients either. Empirical work by Erickson and Whited (2000) demonstrates that the sensitivity of investment to cash ‡ow in regressions including Tobin's Q is to a large extent due to measurement error in Q. Cooper and Ejarque (2002) demonstrates that the statistical signi…cance of cash ‡ow in a standard Q investment regression may re‡ect …rm market power rather than …nancing constraints.[8] Abel and Eberly (2002b) have a similar theoretical point in the absence of any adjustment cost.

We should make clear that none of these criticisms actually disprove the importance of …nancing constraints in in‡uencing …rm investment. Their message is that the use of reduced-form investment regressions where Tobin's Q is meant to control for fundamentals and cash ‡ow to pick up the in‡uence of …nancial market imperfections is dubious.

Some other work has followed di¤erent methods in testing for the presence of …nancing constraints. A sizable strand of the literature, starting with Whited (1992), Bond and Meghir (1994), and Hubbard and Kashyap (1992) has used the investment Euler equation to test whether internal funds a¤ects the …rm's incremental intertemporal investment allocation.[9] Gilchrist and Himmelberg (1999) construct a measure of marginal Q as well as a measure of …nancial factors and include them in investment regressions. Hu and Schiantarelli (1998) estimate an explicit switching regressions models for investment. Whited (2002) ex-

and Carpenter, Fazzari and Petersen (1998) among others.

[7] See also Fazzari, Hubbard and Petersen (2000) and Kaplan and Zingales (2000) as part of the debate that ensued in the literature.

[8] In a related paper, Galeotti and Schiantarelli (1991) have demonstrated that monopolistic competition introduces output in the investment equation in addition to Q.

[9] There are numerous other papers using this approach. Among these are Hubbard, Kashyap and Whited (1995), and Jaramillo, Schiantarelli and Weiss (1996).

amines investment hazard: the probability of undertaking a large investment project as a function of the time since the last project. These papers find support for the hypothesis that financial constraints affect firm investment.

What should be clear from the above discussion is that we are desperately in need of structure in investigating investment. This structure should allow for the existence of both convex and non-convex adjustment costs and specify the channel through which financial frictions bite. In this paper, we formulate such a theoretical model, estimate, and evaluate it. In so doing we are moving beyond simply testing and rejecting a neoclassical model without frictions and instead attempt to provide quantitative estimates of the importance of different frictions, real and financial, on firm investment. In our structural model financial imperfections enter through a premium on the cost of debt that depends on the firm's leverage ratio. Bernanke, Gertler and Gilchrist (1999) review the literature that provides theoretical justification for this formulation.

We estimate the model using indirect inference as proposed by Gourieroux, Monfort and Renault (1993) and Smith (1993). This method involves picking some appropriate regression coefficients or data moments as "benchmarks" that we would like the model to match well. Then, the structural parameters are estimated so that the model, when simulated, generates "benchmarks" as close to those of the actual data as possible. The method is very flexible in allowing the use of a wide selection of "benchmarks." Care needs to be taken, however, so that appropriate ones are selected. Our benchmark is an investment regression involving linear and non-linear terms in shocks to profitability and debt leverage.

We intend to address in this paper questions for German Manufacturing investment such as the following:. 1) What is the relative magnitude of excess cost to debt finance? 2) Is the responsiveness of aggregate investment to aggregate profitability conditions moderated by financing constraints? If so, by how much? 3) What percent of operating profits is expended on the costs of adjusting capital? This is just a partial list of interesting questions that we hope to address. We also intend to construct similar data sets of firm level observations for other euro area countries so that we can make a comparative study of the environment for business investment.

2 Model

We model a monopolistically competitive …rm. In the beginning of period t; …rm i has real capital stock, K_{it}, which re‡ects all investment decisions up to last period, and net …nancial liabilities, B_{it}, which includes both …nancial assets and liabilities (debt, cash, retained income etc.). If B_{it} is positive, it re‡ects the debt stock borrowed last period. On the other hand, if B_{it} is negative, it is retained income that was invested in assets bearing a risk-free return of r, the risk-free market interest rate. We assume that debt contracts are written for one period and, similarly, …nancial assets have a one-period term. Before making any investment decision, the …rm observes the current period aggregate and idiosyncratic pro…tability shocks. Given these state variables, the …rm decides on investment and on the amount of debt that needs to be borrowed (or on the amount of dividend retention). The behavioral assumption we maintain is that …rm managers maximize the present discounted value of dividends, D_{it};paid out to shareholders.

Pro…ts

The …rm's operating pro…ts are given by the following expression:

$$¦ (A_{it}; K_{it}) = A_{it} K_{it}^{\mu} \qquad (1)$$

where $0< \mu < 1$; re‡ecting the degree of monopoly power.[10] A_{it} is the current period pro…tability shock. It contains both an idiosyncratic component, $"_{it}$, as well as an aggregate one, A_t:[11] The buying price of capital, p; is assumed to be constant. We also assume that capital is the only quasi-…xed factor of production, and all variable factors, such as labor and materials, have already been maximized out of the problem. The discount factor, ¯; is …xed. The implied discount rate is assumed to be greater than r, the market interest rate at which the …rm can lend.

[10] This functional form of the operating pro…t function is valid under the assumptions of constant-returns-to-scale Cobb-Douglas production function, constant-elasticity demand function, and ‡exible labor and materials inputs. Alternatively, it could be derived from a decreasing-returns-to-scale Cobb-Douglas production function under perfect or imperfect competition, though this is not the approach we take in our implementation.

[11] The pro…tability shock is a function of technology, demand, wage and materials cost shocks as well as structural parameters. Following Cooper and Haltiwanger (2002), we assume that A_t is a …rst-order, two state Markov process with A_t 2 fA_h; A_lg where h and l denotes high and low value of shocks. The idiosyncratic shock is also a …rst-order Markov process and in our empirical work it takes eleven possible values.

2.1 Adjustment Costs

The firm faces various costs when adjusting its capital stock. Our model is general enough to accommodate both convex and non-convex adjustment costs.

Convex costs

We employ the assumption of a quadratic function, which is common in the literature when describing convex adjustment costs: $\frac{\gamma}{2}\left[\frac{I_{it}}{K_{it}}\right]^2 K_{it}.$ The parameter γ affects the magnitude of total and marginal adjustment costs. The higher is γ the higher is the marginal cost of investing and the lower is the responsiveness of investment to variations in the underlying profitability of capital.

Fixed costs

We also allow for the possibility that there is a component of costs that is fixed when investment is undertaken regardless of the investment's magnitude: $FK_{it}.$ In order for this cost to be relevant at all stages of a firm's life we assume that it is proportional to a firm's size as measured by its capital stock. The parameter F determines the magnitude of fixed costs.

Partial Reversibility

Finally, we allow for the presence of a wedge between the selling and buying prices of capital, namely $p_S \leq p.$

2.2 Financial Market Imperfections

Firms may finance investment out of their retained earnings or by raising funds in the capital markets. Retained funds consist of current operating profits, $\Pi(A_{it}, K_{it}),$ or net financial assets carried over from last period. We assume here that the only source of external finance is through debt and that no new equity may be issued by the firm. In the presence of financial market imperfections, there might be a cost advantage to using internal funds as opposed to external ones. In particular, the cost of borrowing may be higher than he risk-free market interest rate. This external finance premium will depend on the firm's financial health, which may be captured by the ratio of its net worth to total assets. Assuming that capital is the only collateral asset that the firm has then financial health may be measured by the leverage ratio, $\frac{B_{it}}{p_S K_{it}},$ that is the ratio of debt to the resale value of capital. We assign the following functional form to the external finance premium:[12],[13]

$$\eta_{it}(K_{it}, B_{it}) = \alpha \frac{B_{it}}{p_S K_{it}} \qquad (2)$$

Note that this premium exists only when $B > 0$: The firm's lending rate is unaffected. The coefficient α determines the magnitude of external finance premium, and, in turn, the magnitude of the financial market imperfections. The expected sign of α is non-negative. This means that firms maintaining a higher leverage ratio need to pay higher premia. The restriction that no new equity may be issued by the firm or, alternatively, that debt be the marginal source of external finance is introduced through a non-negativity constraint on dividends. We don't think that restricting the firms external finance to only debt and excluding equity is too severe. For most German firms the marginal external source of funds is debt. An ECB study (ECB, 2002) suggests that loans are by far the most important source of external finance. During the period 1998-2000, external financing through new loans averaged 6.7% of GDP. In contrast the gross amount of capital raised by new shares (both listed and non-listed) amounted to 1.3 percent in 1998 (and 1.2 of GDP in 2000).

2.3 Value maximization

The firm manager's dynamic program can be written as follows:

$$V^*(A_{it}, K_{it}, B_{it}) = \max \{V^b(A_{it}, K_{it}, B_{it}), V^s(A_{it}, K_{it}, B_{it}), V^{na}(A_{it}, K_{it}, B_{it})\} \qquad (3)$$

In words, the manager needs to choose optimally between buying capital, with value V^b; selling capital, with value V^s; or undertaking no investment at all, with value V^{na}. The value of each one of these discrete choices, $(j = b, s, na)$, is in turn defined as follows:

[12] There might be some concerns about whether high debt indicates that a firm faces with financial problems or it shows that firms have perfect excess to the debt market so that they have such a high level of debt. Many studies assume that high debt stock relative to the capital stock is an indicator that firms are financially vulnerable since their net worth is low. Some examples of these studies are: Bernanke and Gertler (1990), Bernanke, Campbell and Whited (1990), Whited (1992), Hu and Schiantarelli (1998), and Gilchrist and Himmelberg (1998). When firms are finacially fragile, lenders will take higher risk by lending fund to these firms, so they will charge a higher external finance premium to compansate this risk.

[13] Gilchrist and Himmelberg (1998) use this kind of external finance premium. But they do not assign any functional form to it. Jaramillo, Schiantarelli, and Weiss (1996) use an explicit form of external finance premium, which is linear in the leverage ratio.

$$V^j(A_{it};K_{it};B_{it}) = \max_{\{K_{it+1};B_{it+1}\}} D_{it} + \beta E_{A_{it+1}|A_{it}} V^*(A_{it+1};K_{it+1};B_{it+1}); \tag{4}$$

subject to (1), (2) and the following constraints:

$$D_{it} = \begin{cases} \Pi(A_{it};K_{it}) - C^j(K_{it};I_{it}) + B_{it+1} - (1+r)(1+\eta_{it}(K_{it};B_{it}))B_{it} \\ \qquad \text{when } B_{it} > 0 \\ \Pi(A_{it};K_{it}) - C^j(K_{it};I_{it}) + B_{it+1} - (1+r)B_{it} \text{ when } B_{it} < 0 \end{cases} \tag{5}$$

$$I_{it} = K_{it+1} - (1-\delta)K_{it} \tag{6}$$

$$D_{it} \geq 0 \tag{7}$$

where $V^*(\cdot)$ is the value function, $\beta E_{A_{it+1}|A_{it}} V^*(\cdot)$ is the present discounted future value of the firm, $\eta_{it}(\cdot)$ is the external finance premium, $C(\cdot)$ is the investment cost function, I_{it} stands for investment, δ is the depreciation rate, and i, t are firm and time indexes respectively.

The investment cost, captured by the function $C(\cdot)$; depends on the manager's discrete choice. In the case of positive investment, $j = b$; it contains the purchase cost as well as fixed and convex adjustment costs:

$$C^b(K_{it};I_{it}) = pI_{it} + \frac{\gamma}{2}\left[\frac{I_{it}}{K_{it}}\right]^2 K_{it} + FK_{it} \tag{8}$$

When the firm sells capital, $.j = s$; the costs are:

$$C^s(K_{it};I_{it}) = p_S I_{it} + \frac{\gamma}{2}\left[\frac{I_{it}}{K_{it}}\right]^2 K_{it} + FK_{it} \tag{9}$$

Finally, when no action is undertaken regarding investment, $j = na$; the investment costs are zero:

$$C^{na}(K_{it};I_{it}) = 0 \tag{10}$$

In summary the set of structural parameters is: $\{\beta;\delta;\theta;\gamma;F;p_b;p_s;\alpha\}$: These together with the transition matrix for the profitability shocks (A_{t+1}) determine the behavior of the model.

3 Empirical results

3.1 Data set

Our data are an unbalanced panel of 170 German manufacturing …rms over the period 1992-1999 containing 1163 observations. The data is derived from the AMADEUS database. The …rms are not an unbiased sample of the total manufacturing population, rather they are drawn from the largest German manufacturing …rms. [14] This is mainly because data was not available for smaller manufacturing …rms.[15] The median …rm had a capital stock of 133 million euros (in 1995 prices). Although the sample contains only 170 …rms, they represent more than 20% of the manufacturing industry capital stock. They had a total replacement value of capital stock of 101 billion euro in 1995 , where the total manufacturing industry in Germany had in 1995 a capital stock total of 483 billion euro. The median investment rate is relatively high at 0.16. Although we succeeded in deleting …rm observations from the data when the investment …gure entailed substantial merger or acquisition activity (rather than the buying of new equipment or buildings), we were not able to identify every possible acquisition. So the investment rate probably includes some acquisitions or mergers.

Table 1 shows further summary statistics of the data. Table 2 shows some features of the investment rate. Around 0.7% of the observations entail an investment rate near zero (de…ned as less than 1% in absolute value). At …rst sight this looks small, compared to e.g. Cooper and Haltiwanger (2002) who state that for US manufacturing plants the inaction rate is 8%. However given that our …rms are practically certainly operating multiple plants, a lower inaction rate is not surprising. (For instance suppose each …rm has only two plants with each an inaction rate of 8%, and assume the inaction periods are uncorrelated. This would lead to a …rm inaction rate of approximately 0.6%.) Around 4.7% of the investment rates are negative (as a comparison it is 10.4% in Cooper and Haltiwanger 2002). 38% of the investment observations are above 20%.

[14] Our …nal sample contains the very large well know …rms as e.g. bayer, basf, Volkswagen, bmw and adidas-salomon, but contains also much smaller (but still relatively large) less well know …rms as schwabenverlag, Aqua signal, Buckau Walter.

[15] For more details on sample selection see the appendix

Table 1. Summary Statistics

	mean	median	st.dev	min	max
I_{it}/K_{it-1}	0.19	0.16	0.16	-0.50	0.88
K_{it}	661	133	2194	2	26000
CF_{it}/K_{it-1}	0.30	0.23	0.41	-0.84	3.44

capital stock is in million euros measured in 1995 prices.

Table 2. Features of the distribution of the investment rate

$\lvert I_{it}/K_{it-1}\rvert < 0.01$	0.9%
$\lvert I_{it}/K_{it-1}\rvert < 0.02$	3.3%
$I_{it}/K_{it-1} < 0$	4.7%
$I_{it}/K_{it-1} > 0.20$	38%
$I_{it}/K_{it-1} > 0.25$	25%
$\mathrm{corr}(i_{it-1}; i_{it})$	0.008
$\mathrm{corr}(I_{it}/K_{it-1}; I_{it-1}/K_{it-2})$	0.30

3.2 Methodology

3.2.1 Estimation of the profit function

The profit function is given by

$$\pi(A_{it}; K_{it}) = A_{it}K_{it}^{\theta}$$

We estimate θ, by regressing the log of real profits on the log of the capital stock including time dummies and fixed effects. From our data θ is estimated as 0.34, with a standard error of 0.08.One can show that our estimate of the slope of the profit function, θ; is related to the markup (or price-cost marginal) of the firms (where markup or price cost margin is traditionally defined as price minus marginal cost over marginal cost). The markup is equal to $\frac{\alpha(1-\theta)}{\theta}$, where α is the capital share in gross output.

Calculating the implied markup of our slope parameter estimate lets us gauge how reasonable it is. Assuming a capital share between 0.16 and 0.20, and combining it with our estimate of θ (0.34), this leads to a markup between 31 and 39%. We are not aware of estimates of markups in German manufacturing. However, using four digit S.I.C. manufacturing industry level data for the U.S., Domowitz et al (1988) obtain an average markup of

37% which is similar to ours. They obtain these estimates of the markups using a methodology initially developed by Hall (1986). This methodology exploits the fact that the ratio of cost increase to output increase is equal to marginal cost. Hall (1986) uses the ratio of labor cost increases relative to output increases (correcting for technical progress) to estimate marginal cost and hence markups. Domowitz (1988) et al. show that Hall's estimates are too high due to the fact that he ignores material inputs. Domowitz (1988) et al. show that including material inputs reduces estimated margins by a factor (1-$®_m$), with $®_m$ the share of materials in gross output. More recently Morrison (1992) estimates markups for aggregate U.S. manufacturing in the range of 11% to 23 %. She deviates from former authors by using a production-theory framework where both labor and capital are quasi …xed. It is unresolved in the literature whether these estimates of markups using aggregate data can be compared with those from …rm individual data. One of the reasons is that it is unclear whether the demand equation measured at the aggregate level is that of an industry or that of a representative …rm. (For a discussion see Morrison (1992).

3.2.2 Calculation and decomposition of the pro…t shocks

In principle one could use the pro…t and capital stock data to calculate the pro…t shocks A_{it}. However, we have noticed that measured pro…ts are highly variable and therefore contain much measurement error.[16] One can show that in our theoretical model pro…ts are equal to a …xed factor times the wage bill:

$$¦(A_{it}; K_{it}) = c ¤ w_{it} L_{it} \tag{11}$$

So that we calculate the pro…t shocks (up to a multiplicative factor) using equation (1) and (11) as

$$A_{it}=c = w_{it} L_{it}=K_{it}^{µ} \tag{12}$$

We then decompose the pro…t shocks into a …xed component, and time varying component by regression the log of the pro…t shock on (a constant and) …xed e¤ects.[17] :

[16] Note that this measurement error should not lead to a bias in in the determination of µ since it is measurement error in the "y-variable".

[17] Note that one can not identify the …xed e¤ect from the constant c seperately. However since we are not

$$\log(A_{it}/c) = -\log(c) + a_i + \tilde{a}_{it} \quad (13)$$

The time varying components $\tilde{a}_{it}$ are used in the investment regression. One can further split the time varying component of the shock into the aggregate and the idiosyncratic components: $\tilde{a}_{it} = a_t + a_{it}$. An analysis of variance decomposition of $\tilde{a}_{it}$ into those two components reveals that practically all variation is due to the idiosyncratic time varying component.

Table 3. Features of the (firm demeaned) profit shocks (in logs): $\tilde{a}_{it}$

minimum: -0.80
maximum: 0.49
std. dev. $\tilde{a}_{it}$:0.118
std. dev. a_t 0.018
standard deviation a_{it}: 0.118
autocorrelation $\tilde{a}_{it}$: 0.48

3.3 The relationship between investment, profitability shocks and the leverage ratio.

We study the following relationship between investment, profitability and the leverage ratio.

$$\tilde{i}_{it} = \psi_0 + \psi_1 \tilde{a}_{it} + \psi_2 (\tilde{a}_{it})^2 + \psi_3 a_{i,t-1} + \psi_4 \widetilde{B_{it}/K_{it}} + \psi_4 (\tilde{a}_{it} \widetilde{B_{it}/K_{it}})^2 + \mu_t + \varepsilon_{it}$$

where $\tilde{i}_{it}$ is the deviation of the investment rate at firm in year t from the firm specific mean, $\tilde{a}_{it}$ is the demeaned profit shock , $\widetilde{B_{it}/K_{it}}$ is the demeaned leverage ratio and $(\tilde{a}_{it} \widetilde{B_{it}/K_{it}})$ is the product of both squared. This relationship was suggested by careful examination of the policy function for investment. Profitability shocks as well as variations

interested in the level of the parameter A_{it}, but rather its variation, this is irrelevant for our purposes. A oneway analysis of variance on the level of the profitability schock (in logs) A_{it}/caccross firms reveals that the estimated standard deviation of the firm specific profit schock is 0.98 (i.e the accros firm variation of the firm specific effect), while the idionsyncratic (including time effect) has a standard deviation of 0.129. In the sample 98.8 % of the variation in the profit level (in logs) is across firms.

in the debt leverage ratio seem to have non-linear effects on investment. In particular, the last term was suggested by the observation that variations in the debt leverage ratio have effect on investment mostly when debt is high, capital is low and profitability is high. In simulations of the model we confirmed that small variations in the structural parameters produced large variations in the coefficients of the above reduced form regression. This is a necessary condition for identification of the structural parameters in the indirect inference procedure that we follow later in this paper.

Table 4. Summary Statistics of the regression variables

	mean	st.dev	min	max
$\tilde{i}_{it}$	0.00	0.13	-0.58	0.63
$\tilde{\varepsilon}_{it}$	0.00	0.11	-0.80	0.46
$(\tilde{\varepsilon}_{it})^2$	0.01	0.03	0.00	0.64
$\tilde{\varepsilon}_{it-1}$	0.00	0.11	-0.52	0.49
B_{it}/K_{it}	0.00	0.20	-1.24	0.87
$(\tilde{\varepsilon}_{it}B_{it}/K_{it})^2$	0.00	0.004	0.00	0.08

Table 5. Correlation matrix of the regression variables

	$\tilde{i}_{it}$	$\tilde{\varepsilon}_{it}$	$(\tilde{\varepsilon}_{it})^2$	$\tilde{\varepsilon}_{it-1}$	B_{it}/K_{it}	$(\tilde{\varepsilon}_{it}B_{it}/K_{it})^2$
$\tilde{i}_{it}$	1					
$\tilde{\varepsilon}_{it}$	0.32	1				
$(\tilde{\varepsilon}_{it})^2$	-0.04	-0.23	1			
$\tilde{\varepsilon}_{it-1}$	-0.01	0.48	0.06	1		
B_{it}/K_{it}	-0.27	-0.18	0.00	0.01	1	
$(\tilde{\varepsilon}_{it}B_{it}/K_{it})^2$	-0.08	0.09	0.38	0.09	-0.19	1

Table 4 gives the summary statistics of the regression variables. Table 5 gives the correlation matrix. The investment rate is positively correlated with the contemporaneous profit shock (correlation is 0.32) as one should expect and is negatively correlated with beginning of period leverage ratio (correlation is -0.27). Also the shocks are positively autocorrelated (correlation of the shock with its lag of 0.48). The profit shocks are also negatively correlated with the leverage ratio indicating that higher leveraged firms are more likely to face negative profit shocks. The lagged profit shock however is practically uncorrelated with the leverage ratio.

Table 6 gives the regression results. These show that there is an economically important relationship between the profit shocks the leverage ratio and investment. A 1 standard deviation positive pro…t shock (which implies an 11% increase in pro…ts) increases the investment rate by 6.7 percentage points. The relationship is somewhat nonlinear: 5.9 percentage points is coming from the shock and 0.8 percentage points from the shock squared. (The calculation is 0.11*0.533+0.11*0.11*0.659).

The negative coe¢cient on the product between the pro…t shock and the leverage implies that the e¤ect of a positive pro…t shock on investment is dampened for …rms with higher leverage. For instance a …rm with a 1 standard deviation higher leverage (i.e 0.20) the dampening e¤ect would be 0.3 percentage points (i.e. ((0.11*0.20)^2)*6.52). Also, independently of the pro…t shocks, …rms with higher leverage invest less. A …rm with a 1 standard deviation higher leverage (i.e 0.20) has an investment rate that is lower by 0.3 percentage points.

Given the fact that in the data pro…t shocks are highly correlated while the demeaned investment rate is not, it is not surprising that the lagged shock has a negative sign. Since a positive shock is likely to be followed by a positive shock this implies a dampened behavior of the investment rate.

TABLE 6: Regression of investment on pro…tability shocks and leverage

Coe¢cient	
a_{it}	0.533* (0.056)
$(a_{it})^2$	0.659* (0.157)
a_{it-1}	-0.276*(0.054)
B_{it}/K_{it}	-0.156* (0.025)
$(a_{it}B_{it}/K_{it})^2$	-6.52* (1.693)

* signi…cant at the 1% level. Robust standard errors (adj Rsq=0.22)

3.4 Using the distribution of the pro…t shocks in simulating the model

The theoretical investment model can be simulated when its parameters (μ; °; p_s; ®) are given a value and the pro…tability shocks $A_{it}$are given a distribution. For the simulation, the distribution has to be discretised. One can abstract from the idiosyncratic …xed part of the pro…tability shock (without loss of generality we set it equal to 1 in the simulation)

	-0.48885	-0.14633	-0.07996	-0.04659	-0.0209	0.001595	0.022444	0.046227	0.079789	0.149245	0.328455	Total
-0.48885	**0.31**	0.31	0.12	0.10	0.00	0.00	0.00	0.05	0.07	0.00	0.05	100
-0.14633	0.10	**0.29**	0.28	0.13	0.03	0.05	0.02	0.01	0.07	0.02	0.00	100
-0.07996	0.04	0.19	**0.14**	0.17	0.14	0.05	0.08	0.07	0.06	0.03	0.01	100
-0.04659	0.03	0.07	0.10	**0.17**	0.14	0.18	0.08	0.14	0.06	0.03	0.01	100
-0.0209	0.02	0.08	0.11	0.17	**0.15**	0.15	0.12	0.08	0.10	0.03	0.01	100
0.001595	0.00	0.03	0.07	0.15	0.18	**0.18**	0.15	0.12	0.08	0.03	0.01	100
0.022444	0.02	0.03	0.05	0.09	0.18	0.09	**0.18**	0.17	0.14	0.04	0.01	100
0.046227	0.00	0.04	0.07	0.05	0.11	0.09	0.19	**0.17**	0.17	0.10	0.02	100
0.079789	0.03	0.04	0.04	0.02	0.06	0.08	0.13	0.13	**0.13**	0.26	0.07	100
0.149245	0.03	0.05	0.05	0.04	0.04	0.05	0.07	0.13	0.14	**0.26**	0.13	100
0.328455	0.05	0.00	0.02	0.00	0.05	0.02	0.00	0.02	0.15	0.37	**0.32**	100

Figure 1: Transition matrix

We discretise the distribution of the aggregate part of the pro…tability shock a_t and the time varying idiosyncratic part a_{it}: Since the standard deviation of the aggregate part is very small (0.02) compared with the standard deviation of the time-varying idiosyncratic part (0.12), we let the aggregate part only take on two values -0.02 and +0.02 (which imply A_t = 1:02 or 0:98). The probability that a high aggregate shock is followed by a low one was calculated as 0.40. The transition matrix is given below.

Transition matrix aggregate part of pro…tability shock

	-0.02	0.02
-0.02	0.6	0.4
0.02	0.4	0.6

For the time varying idiosyncratic part a_{it} we discretised nonparametrically the empirical distribution into 11 bins (9 bins each containing 10 percent of the observations and two outlier bins each containing 5 percent of the observations. The transition matrix was also calculated nonparametrically.

The high probabilities at the diagonal and both above and below the diagonal re‡ect the high autocorrelation of the pro…tability shocks.

3.5 Structural Estimation

We proceed by …xing *a priori* some of the structural parameters of the model. In particular, we set $r = 0{:}0413; ^{-} = 1{=}(1 + d); d = 0{:}0549; \pm = 0{:}085; p_b = 1;$ and $\mu = 0{:}34$: The interest rate r has two functions in our model. First it is the renumeration interest rate for the …rm if it has negative debt , i.e. if it accumulates funds. Second it is the lowest marginal interest rate at which the …rm can borrow if it has zero debt. It is set at 4.13% which is the average real yield on industry bonds in Germany over the period 1966-2002. The marginal interest rate for …rms with positive debt is $r + ®\frac{B_{it}}{p_S K_{it}} + r®\frac{B_{it}}{p_S K_{it}}$. The discount rate is set at 5.49 % . It is the average real yield on German stocks (measured by the DAX index) over the period 1966-2002. Taking the discount rate d higher then r , makes sure that a …rm has an incentive to make dividend payments and not accumulate an in…nite amount of assets. Say a …rm makes positive pro…ts, has no debt and has enough funds for investment. If $r > d$ the …rm simple accumulate funds and never pays them out. Note that if such a …rm would never face negative shocks it would have an in…nite value since the rate at which assets would accumulate r would be larger than the discount rate. Note that since we have $d > r$, the …rm has an incentive to take positive debt to …nance itself. Only taking positive debt can equate the discount rate with the marginal cost of debt …nance.

The depreciation rate is based on our estimates with data from German manufacturing industry and is described in the Appendix. The pro…tability curvature parameter, µ; was estimated from our data. The vector of remaining structural parameters to be estimated is called $£ ´ (®; °; p_S; F)$. We will estimate these using the indirect inference method.[18] This approach involves several well-de…ned steps.

First, we solve the …rm's dynamic programming problem for arbitrary values of the structural parameters £ and generate the corresponding optimal policy functions.[19] Second, we use these policy functions and arbitrary initial conditions to generate simulated data. In particular, we generate 14 arti…cial panels comprising data for 170 …rms for 7 years. Third, this simulated data set is used to calculate the model analogues of the coe¢cients and/or moments we obtained using actual data. Letting $a_{it} = \ln(A_{it})$; the reduced form regression on which we base our indirect inference is

$$\text{¶}_{it} = \tilde{A}_1 \mathbf{a}_{it} + \tilde{A}_2(\mathbf{a}_{it})^2 + \tilde{A}_3 B\,\underline{\mathbf{g}}K + \tilde{A}_4(\mathbf{a}_{it}\; B\,\underline{\mathbf{g}}K)^2 + u_{it} \qquad (14)$$

[18] This approach was introduced by Gourieroux, and Monfort (1996), Gourieroux, Monfort and Renault (1993), and Smith (1993). The following are some examples of empirical papers using this approach. Cooper and Haltiwanger (2002) estimate an investment model with both convex and non-convex adjustment costs. Adda and Cooper (2002) study the impact of scrapping subsidies on new car purchases. The distribution of price adjustment costs are estimated by Willis (1999). Cooper and Ejarque (2001) investigate the role of market power in the Q theory.

[19] The problemm is solved using the value function iteration method. Rust (1987a and 1987b) applied this method in his studies. Christiano (1990a and 1990b) showed that it method performs better than linear-quadratic approximation in the context of the stochastic growth model.

where $\frac{I}{K}_{it}$ is the investment rate at firm i in period t, and B/K is the ratio of debt to the capital stock.[20] All variables are converted to deviations from their firm-specific means.

Cash flow for the simulated data is calculated according to

$$CF_{it} = \begin{cases} \Pi(A_{it}, K_{it}) - (1+r)(1+\eta_{it})B_{it} + B_{it} & \text{when } B_{it} >= 0 \\ \Pi(A_{it}, K_{it}) - rB_{it} & \text{when } B_{it} < 0 \end{cases} \qquad (15)$$

Fourth, we check whether the distance between Ψ^d, the vector of coefficients from the actual data, and $\Psi^s(\Theta)$, the vector of coefficients from data simulated given Θ, are arbitrarily close. If they are not, update Θ in a manner that is likely to make this distance smaller and go back to the first step.

More formally, we try to minimize with respect to Θ the following quadratic function:

$$\min_{\Theta} J(\Theta) = (\Psi^d - \Psi^s(\Theta))' W (\Psi^d - \Psi^s(\Theta))$$

where W is a weighting matrix.[21] In practice, we use the method of simulated annealing in order to minimize $J(\Theta)$.[22]

3.6 Results

The point estimates of the structural parameters are given in Table 7 and look quite reasonable. The parameter α determines the external finance premium. An increase of the leverage ratio of 1 standard deviation, i.e. by 20 percentage points increases the external

[20] It is important that the moments and the coefficients used be responsive to changes in the underlying structural parameters of the model. When that is the case, as specified by Gourieroux and Monfort (1996), minimizing the distance between the simulated data moments and the actual data moments will generate consistent estimates of the structural parameters since the simulated moments depend on the structural parameters.

[21] Since the number of structural parameters is equal to the number of coefficients that we are trying to match we have many choices of matrix to use. An example is a 4×4 diagonal matrix with ones. In the implementation we use the inverse of the variance-covariance matrix of Ψ^d.

[22] There are a couple of advantages of this method compared to the conventional algorithms. First of all, this method explores the function's entire surface, and tries to optimize the function while moving both uphill and downhill. Thus it is almost independent of starting values. The other advantage of this method is that it can escape from local optima, and still find the global optimum by moving uphill and downhill. Further, the assumptions of the simulated annealing method regarding functional forms are less strict. Goffe, Ferrier, and Rogers (1994) provide evidence that this algorithm is quite good in finding the global optimum for difficult functions.

finance premium by 0.56 percentage points (i.e. 56 basis points). The parameters γ and F affect the cost of investing. The total cost of investment as a fraction of the capital stock is defined as:

$C^b(K_{it}; I_{it})/K_{it} = p\frac{I_{it}}{K_{it}} + \frac{\gamma}{2}\left[\frac{I_{it}}{K_{it}}\right]^2 + F$. At the mean investment rate of 0.19 the convex adjustment cost, $\frac{\gamma}{2}\left[\frac{I_{it}}{K_{it}}\right]^2$, is 0.007, the fixed cost F; is 0.021. In other words, when the investment rate is 0.19, total convex adjustment costs are 3.7 percent (or 0.007/0.19) of the purchase cost, total fixed cost are 10 percent of the purchase cost of investing (0.021/0.19). Thus, it seems that fixed costs of adjustment are quantitatively more important than convex ones. There is also evidence of partial irreversibility as the resale price of installed capital is estimated to be around 83 percent the purchase price. However the resale price parameter is highly imprecise.

Table 7: Estimates of the structural parameters

Parameter	estimate	std.error
α	0.028	0.009
γ	0.405	0.025
F	0.021	0.004
p_s	0.830	21.09

Table 8: Regression of investment on profitability shocks and leverage: Actual versus simulated data

Coefficient	Data	Std. error	Model	Std.error	Difference
a_{it}	0.533	(0.056)	0.466	(0.008)	0.067
$(a_{it})^2$	0.659	(0.157)	0.531	(0.073)	0.128
a_{it-1}	-0.276	(0.054)	-0.367	(0.007)	-0.091
B_{it}/K_{it}	-0.156	(0.025)	-0.148	(0.056)	0.008
$(a_{it}B_{it}/K_{it})^2$	-6.52	(1.693)	-4.789	(1.57)	1.731

Table 8 shows the regression coefficients of our reduced form regression of investment on the profitability shocks and leverage using the actual data and the simulated data (where the simulated data were obtained using the structural parameters as in Table 7). The table also reports the difference between the coefficients when using actual and simulated data. The coefficients of our reduced form investment regression using the actual data are reasonably well matched with those of regression using the simulated data. The coefficients of true and simulated data on the shock and the leverage ratio are less than 1 standard error (measured by the actual data st. error) apart. The coefficients of the shock squared are practically 1 standard error apart. The worst fit is found in the lagged shock and the interaction between the shock and the leverage ratio.

Table 9: Moments of actual data versus simulated data

	Data	Model
corr(a_{it}; i_{it})	0.33	0.25
$I_{it}/K_{it-1} > 0.20$	0.38	0.28
corr(a_{it}; B_{it}/K_{it})	-0.18	0.01
corr(i_{it}; B_{it}/K_{it})	-0.27	-0.01
corr(i_{it-1}; i_{it})	0.008	-0.34
corr(B_{it}/K_{it}, B_{it-1}/K_{it-1})	0.42	-0.20

Table 9 shows some other moments of the actual and simulated data. The contemporaneous correlation of the profitability shock with the investment rate is very similar between actual and simulated data implying that the model captures well this contemporaneous correlation. Also the nonlinear effect of the profitability shocks is well captured as evidenced by a similar fraction of firms having investment bursts. The contemporaneous correlation between the profitability shock and the leverage ratio is however not so well captured. Where it is negative in the actual data it is absent in the simulated data. Related to this, the contemporaneous correlation between the leverage ratio and the investment rate is much more negative in the data.

The dynamics of the simulated data seems to be different than the dynamics of the actual data. The autocorrelation of the investment rate is dramatically different. Where there is no autocorrelation in the actual data, there is a negative one in the simulated data. Also the autocorrelation of the debt ratio is highly positive in the actual data while it is negative in the simulated data. Trying to understand why this is the case, it is interesting to note that the interaction term between the leverage ratio and the shock is not well-matched by the model. It is possible that measurement error in the leverage ratio is the cause of some of the difference in dynamics. There is only one type of debt in the theoretical model. This debt also necessarily moves together with any investment or dividend decision that are partly explained by profitability shocks. In the data however firms have trade debt, trade credit, debt to finance inventories etc. These types of debt can move completely independently of investment or dividend decisions. This could lead to such drastically different autocorrelation patterns in the actual versus simulated data.

4 APPENDIX: Sample Selection

The major source of the data is the AMADEUS database from Bureau Van Dijk (releases CD-rom June 2001 and September 1997). This is a database including …rm balance sheet and pro…t and loss information for more than 30 European countries. We only use the information on the German …rms. Our analysis is concentrated on the largest German manufacturing …rms over the period 1992-1999.[23]

The elimination of the …rms is conducted in a number of steps.

1. We only use consolidated accounts. This means that data are all on the group level (capital stock, assets, turnover, etc.) There are 1334 …rms (manufacturing and non-manufacturing) which have at least 1 year of consolidated accounts. The reason why we concentrate on consolidated accounts are threefold. First, unconsolidated accounts can give a very misleading picture of the true nature of the …rm. It is customary that the output of a large …rm is usually produced over multiple plants, each (or a few taken together) with own legal identity and own unconsolidated account. For instance, BASF AG, has a consolidated turnover of around 30 billion euro, where it has an unconsolidated one of around 11 billion euro. Second, the true …nancial boundaries of the …rms are the group not the individual plants. For instance for investment purposes, cash ‡ow generated by one plant can easily be transferred to other plants. Third, limiting ourselves to consolidated data makes our study more comparable with US studies based on Compustat. Compustat contains consolidated data.

2.We only keep manufacturing …rms which have at least 7 years of consecutive information on book value of capital stock and depreciation. This leads to 200 …rms.

3. We only keep …rms if they have pro…ts and cash ‡ow information. This leads to 170 …rms

4. We do not use all observations. We checked on the websites of many companies and found that if the investment rate was higher than 0.9 (90%) this practically always was

[23] Most German …rms have only minor legal obligations to provide accounting information. This information is not su¢cient to perform the study in this paper, since it does not include capital stock information. For instance, the June 2001 CD-rom contains accounting information on 39965 …rms (both manufacturing and non-manufacturing …rms), however 32832 have only limited accounting information. In general these …rms are relatively small or are subsidiaries of larger …rms.

measuring a merger or acquisition. We deleted all observations for which the investment rate was over 90% . We also deleted either the years before or after these investment rates of 90% (depending on what rendered the most data left over), to account for the fact that the …rm could change substantially as a result of the merger or acquisition. This leads to our …nal dataset of 170 …rms on 1163 observations. The dataset is unbalanced. However, each …rm has at least 3 observations. On average, a …rm has 6.8 observations. The maximum number of observations for a …rm is 8.

These 170, …rms are truly the larger ones. They had a total replacement value of capital stock of 101 billion euro in 1995 , where the total manufacturing industry in Germany had in 1995 a capital stock total of 483 billion euro.

4.1 Description of the variables:

4.1.1 Raw variables from the CD-rom:

FIAS: Fixed assets; represents the book value of all …xed assets of the …rm, including building and structures, machinery and equipment, intangible …xed assets and …nancial …xed assets (share ownership in other companies)

OFAS: other …xed assets, are mainly …nancial …xed assets.

OPPL: operating pro…t or loss

DEPR: depreciation

PL: pro…t or loss of the year, is operating pro…ts after exceptional items, taxation and interest payments.

STAF: wage bill of the …rm

4.1.2 Constructed variables:

book value capital stock, K_t^b : The book value of the capital stock was constructed by the calculation FIAS-OFAS.

investment price de‡ator, P_t^I: was constructed by dividing aggregate industry investment data in current and prices of 1995.

investment at current prices, I_t^c : The AMADEUS database does not give gross investment …gures directly. They have to be calculated using depreciation and capital stock numbers. We use the accounting identity : $I_t^c = K_t^b$ ¡ $K_{t¡1}^b + Dep_t$

real investment, I_t :is constructed as investment at current prices de‡ated by the investment price de‡ator $I_t^c = P_t^I$.

real capital stock K_t: The capital stock was constructed using the perpetual inventory method. The book value of the …rst year was multiplied by a factor $1.26/P_t^I$ to convert the book value into replacement value at 1995 prices. The factor 1.26 was derived from aggregate German data by dividing the net capital stock in manufacturing at replacement prices by the net capital stock at historical acquisition prices. The depreciation rates were constructed using aggregate industryl evel data. The depreciation rates are between 6 and 13 percent. The average depreciation rate is 8.5 percent. The perpetual inventory formula used is $K_t = (1$ ¡ ±$)K_{t¡1} + I_t$

investment rate $\frac{I_t}{K_{t¡1}}$: constructed as $I_t$divided by $K_{t¡1}$:

real pro…ts ¼$_t$: are constructed as operating pro…ts plus depreciation (OPPL+DEPR) de‡ated by the German GDP-de‡ator.

real cash ‡ow CF_{it}: are constructed as pro…ts or loss plus depreciation (PL+DEPR) de‡ated by the German GDP-de‡ator.

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