Real versus Financial Frictions to Capital Investment*

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January 2006

Abstract

We formulate and estimate a structural model of firm investment behavior that specifies the exact channel through which financial frictions bite. The model also allows for the existence of both convex and non-convex costs to adjusting capital. Essentially, we move beyond simply testing and rejecting a neoclassical model without frictions. Our quantitative estimates show that both real and financial frictions have an important effect on firm investment dynamics.

Keywords: investment, adjustment costs, financing constraints .
JEL Classification Number: E22

* We would like to thank Steve Bond, Fabio Canova, Robert Chirinko, Jason Cummins, Vitor Gaspar, Simon Gilchrist, John Haltiwanger, Tulio Japelli, Toni Whited, seminar participants at the University of Maryland, UC Davis, Ghent University, European Central Bank, the Federal Reserve Board, ECB/IMOP Workshop on Dynamic Macroeconomics, SED Conference, EEA-ESEM 2004 and the 11th International Conference on Panel data for useful comments. E:mail philip.vermeulen@ecb.int

1 Introduction

Investment is an important component of aggregate activity and much effort 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 firm's capital investment decision. It is fair to say that the initial empirical results of this research have been largely disappointing. Briefly, the estimates of investment responsiveness to fundamentals have been very low whereas output terms (such as profits) have been very significant contrary to theoretical implications. This has continuously set a challenge on empirical work.

The research of the last fifteen years has experienced two breakthroughs. In reverse chronological order, one emphasizes the importance of nonlinearities and the other of financing constraints. Below we review briefly these two influential strands.

Nonlinearity

This literature argues that the apparent failures of neoclassical theory are a result of misspecification of the costs that are relevant in the capital adjustment decision. In particular, irreversibilities and fixed costs to investment may lead firms 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

[1] See Tobin (1969), Lucas (1967), Mussa (1977), Abel (1980) and Hayashi(1982), for seminal contributions as well as Abel (1990) for a review and link to Jorgenson's (1963) user cost concept.

investment to fundamentals.[2]

One of the first empirical contributions in this mold is Doms and Dunne (1998) who show that in a sample of U.S. manufacturing establishments about 72 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 disproportionately larger for a larger gap. Cooper, Haltiwanger and Power (1999) and Nilsen and Schiantarelli (2000) 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) find that investment responsiveness to Tobin's Q is highly non-linear. Finally, Ramey and Shapiro (2001) find 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 influential paper by Cooper and Haltiwanger (2003) provides structural estimates supporting the existence of both convex and fixed 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 coefficients based on regressions of investment on Q.[3]

Financing constraints

[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 fixed costs was stressed by Abel and Eberly (1994), Caballero and Leahy (1996), Caballero and Engel (1998), and Caballero and Engel (1999), among others.

[3]Abel and Eberly (2002b and 2003) provide some fresh models resulting in the second lesson above.

Firms rely mainly on internal sources of funds to finance investment.[4] This may provide 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 financial market imperfections and testing it at the firm level. Their basic working hypothesis is that the sensitivity of investment to cash flow should be higher for firms that face a larger wedge in the cost of internal and external funds (*monotonicity hypothesis*). They argue they could identify *a priori* liquidity constrained firms and then demonstrated for these a high sensitivity of investment to cash flows. On the other hand, Tobin's Q appears to have only a marginal impact on investment for these firms.[5] [6]

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

Other criticisms have arisen too. Gomes (2001) demonstrates that the

[4]Ross, Westerfield, and Jordan (1999) document that firms 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 firms. See Schiantarelli (1996) and Hubbard (1998) for a survey.

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

existence of financing constraints is not sufficient to establish cash flow as a significant regressor in standard investment regressions that include Q. Furthermore, financing constraints are not necessary to obtain significant cash flow coefficients either. Empirical work by Erickson and Whited (2000) demonstrates that the sensitivity of investment to cash flow in regressions including Tobin's Q is to a large extent due to measurement error in Q. Cooper and Ejarque (2003*a*) demonstrates that the statistical significance of cash flow in a standard Q investment regression may reflect firm market power rather than financing constraints.[8] Abel and Eberly (2003) 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 financing constraints in influencing firm investment. Their message is that the use of reduced-form investment regressions where Tobin's Q is meant to control for fundamentals and cash flow to pick up the influence of financial market imperfections is dubious.

Some other work has followed different methods in testing for the presence of financing 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 affect the firm's incremental intertemporal investment allocation.[9] Gilchrist and Himmelberg (1999) construct a measure of marginal Q as well as a measure of financial factors and include them in investment regressions. Hu and Schiantarelli (1998) estimate an explicit switching regressions model for investment. Whited (2004) examines the effects of external finance constraints on a capital stock adjustment hazard: the probability of undertaking a large

[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).

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.

Despite the importance of both financial imperfections and nonconvexities in determining investment, there is only a limited number of attempts to integrate these two lines of theory. For example, the theoretical model created by Lensink and Sterken (2002) combines credit market imperfections and uncertainty about investment returns, which might be caused by irreversibility of 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.[10] 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 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 "bench-

[10] Bayraktar (2002) constructs a similar model combining different types of costs in the capital adjustment process and financial market imperfections. But this model has been simulated in a way to explain the investment behavior of U.S. manufacturing firms.

marks" 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 benchmarks include moments of the distribution of investment rates as well as coefficients from an investment regression involving profitability shocks and debt leverage.

In section 2 we develop a model of optimal investment behavior of a firm with nonconvex and convex adjustment costs and financing constraints. Section 3 contains the empirical results of the estimation by indirect inference and the evaluation of the model. Section 4 concludes.

2 Model

We model a monopolistically competitive firm. In the beginning of period t, firm i has real capital stock, K_{it}, which reflects all investment decisions up to last period, and net financial liabilities, B_{it}, which includes both financial assets and liabilities (debt, cash, retained income etc.). If B_{it} is positive, it reflects 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, financial assets have a one-period term. Before making any investment decision, the firm observes the current period aggregate and idiosyncratic profitability shocks. Given these state variables, the firm 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 firm managers maximize the present discounted value of dividends, D_{it}, paid out to shareholders.

Profits

The firm's operating profits are given by the following expression:

$$\Pi(A_{it}, K_{it}) = A_{it} K_{it}^{\theta}, \tag{1}$$

where $0 < \theta < 1$, reflecting the degree of monopoly power.[11] A_{it} is the current period profitability shock. It may contain both an idiosyncratic component as well as an aggregate one.[12] The buying price of capital, p, is assumed to be constant. We also assume that capital is the only quasi-fixed factor of production, and all variable factors, such as labor and materials, have already been maximized out of the problem. The discount factor, β, is fixed. The implied discount rate is assumed to be greater than r, the market interest rate at which the firm can lend.

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.[13]

[11] This functional form of the operating profit function is valid under the assumptions of constant-returns-to-scale Cobb-Douglas production function, constant-elasticity demand function, and flexible 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.

[12] The profitability shock is a function of technology, demand, wage, and materials cost shocks as well as structural parameters. Following Cooper and Haltiwanger (2003), we assume that the aggregate shock component, A_t, is a first-order, two state Markov process with $A_t \in \{A_h, A_l\}$ where h and l denotes high and low value of shocks. The idiosyncratic shock is also a first-order Markov process and in our empirical work it takes eleven possible values.

[13] In an earlier version of this paper we also allowed for the possibility of partial reversibility of capital. Our estimates of a discount in the resale price of capital were insignificantly different from zero so we have dropped this feature. Given that the results in Ramey and Shapiro (2001) and casual observation point to the existence of (at times) large discounts, this result is puzzling. We believe that we cannot identify the resale price discount with our data as our observations come exclusively from relatively successful, continuing firms. Essentially, in order to identify the discount one needs a fair amount of observations with large negative profitability shocks, which is not the case in our data.

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: $F \times K_{it}$. 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.

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.[14] 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 the 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

[14] Chirinko (1997) constructs a theoretical framework to examine the impact of financial constraints on the specification of Q investment equations. His model allows for debt and equity finance. In our model we excluded equity finance since for most German firms the marginal external source of funds is debt as indicated below.

that the firm has then financial health may be measured by the leverage ratio, $\frac{B_{it}}{K_{it}}$, that is the ratio of debt to the value of capital. We assign the following functional form to the external finance premium:[15]

$$\eta_{it}(K_{it}, B_{it}) = \alpha \frac{B_{it}}{K_{it}}. \tag{2}$$

Note that this premium exists only when $B > 0$. The firm's lending rate is unaffected. The coefficient α determines the magnitude of the 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.

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. Lenders to these firms incur default risk and charge an external finance premium.[16] Pratap and Rendon (2003) gives theoretical justification for the form we use to capture financial market imperfections. That paper shows that risk-neutral, perfectly competitive lenders dealing with firms that may default on debt and exit their industry optimally charge a premium over the risk-free rate that depends positively on firm debt and negatively on firm capital. Here we abstract from modelling bankruptcy and default but capture their effect on investment behavior through a debt interest premium.

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 do not think that restricting the firms external finance to only debt and excluding equity is too

[15] 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.

[16] 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).

severe. For most German firms the marginal external source of funds is debt. An European Central Bank 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 percent 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 percent of GDP in 2000).

2.3 Value Maximization

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

$$V^*(A_{it}, K_{it}, B_{it}) = \max \{V^a(A_{it}, K_{it}, B_{it}), V^{na}(A_{it}, K_{it}, B_{it})\}. \tag{3}$$

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

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

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

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

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

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

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 non-zero investment, $j = a$, $C(\cdot)$ contains the purchase cost as well as fixed and convex adjustment costs:

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

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

$$C^{na}(K_{it}, I_{it}) = 0. \tag{9}$$

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

3 Empirical Results

3.1 Data Set

Our data set is an unbalanced panel of 170 German manufacturing firms over the period 1992-1999 containing 1163 observations. It is derived from the AMADEUS database. The firms are not an unbiased sample of the total manufacturing population, rather they are drawn from the largest German manufacturing firms.[17] This is mainly because data are not available for smaller manufacturing firms.[18] The median firm in our sample has a capital

[17] Our final sample contains not only very large well known firms such as Bayer, BASF, Volkswagen, BMW, and Adidas-Salomon, but also much smaller (but still relatively large) less well known firms such as Schwabenverlag, Aqua Signal, and Buckau Walter.

[18] For more details on sample selection see the appendix.

stock of 133 million euros in 1995 prices. Although the sample contains only 170 firms, they represent more than 20 percent of the manufacturing industry capital stock. While the total replacement value of these firms' capital stock in 1995 was 101 billion euro, it was 483 billion euro for the whole manufacturing industry in Germany. The median investment rate is relatively high at 0.16. We checked company annual reports and the financial press in order to identify major merger or acquisition activities. We deleted firm observations from our data sample when the investment figure entailed such activities (rather than buying of new equipment or buildings). However, despite our best intentions, there is a possibility that we could not identify every possible acquisition. So the investment rate may include minor acquisitions or mergers.

Table 1 contains further summary statistics of the data sample. Table 2 shows some features of the investment rate. Around 0.7 percent of the observations entail an investment rate near zero, which is defined as less than 1 percent in absolute value. At first sight this looks small, compared to values found, for example by Cooper and Haltiwanger (2003) who state that the inaction rate is 8 percent for US manufacturing plants. However given that our firms are, to a large degree, operating multiple plants, a lower inaction rate is not surprising. For instance, suppose a firm operates two plants each having an inaction rate of 8 percent, and also assume that the inaction periods are uncorrelated. This would lead to a firm-level inaction rate of approximately 0.6 percent per year. Table 2 also presents that around 4.7 percent of the investment rates are negative, which was 10.4 percent in Cooper and Haltiwanger (2003). Finally, 38 percent of investment observations are above 20 percent, which is often used as a cutoff value to characterize spikes.

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

Note: 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%
$\text{corr}(\widetilde{i_{it-1}}, \widetilde{i_{it}})$	0.008
$\text{corr}(I_{it}/K_{it-1}, I_{it-1}/K_{it-2})$	0.30

Note: $\widetilde{i_{it}}$ is the deviation of the investment rate at firm i in year t from the firm specific mean.

3.2 Profitability and Shocks

In our model, the profitability shocks, A_{it}, are the only exogenous state variable. They represent the confluence of demand and technology shocks. Our empirical strategy involves identifying these shocks directly in the data through estimating the profit function given in Equation (1). This provides us with an estimate of the profit function's slope parameter, θ, and an estimate of the transition matrix of the profit shocks.

3.2.1 Estimation of the Profit Function and the Profit Shocks

First, we need a consistent estimate of θ, the slope of the profit function. The profit function is given by

$$\Pi(A_{it}, K_{it}) = A_{it} K_{it}^{\theta}, \tag{10}$$

where the productivity shock at time t, $A_{it} = e^{a_i + a_t + a_{it}}$, is decomposed into a firm fixed effect, a_i, an aggregate time effect, a_t, and an idiosyncratic component, a_{it}. The slope of the profit function, $0 < \theta < 1$, reflects the degree of monopoly power. We allow for autocorrelation in the idiosyncratic component, i.e. we assume that a_{it} follows an AR(1) process:

$$a_{it} = \rho a_{it-1} + \epsilon_{it}, \tag{11}$$

where ϵ_{it} is i.i.d.

Taking logs and quasi-differencing the profit function, on the one hand, and first-differencing it, on the other hand, we get the following two equations:

$$\pi_{it} = a_i^* + a_t^* + \rho\pi_{it-1} + \theta k_{it} - \theta\rho k_{it-1} + \epsilon_{it}, \tag{12}$$

$$\triangle\ \pi_{it} = \triangle\ a_t^* + \rho \triangle \pi_{it-1} + \theta \triangle k_{it} - \theta\rho \triangle k_{it-1} + \triangle\ \epsilon_{it}, \tag{13}$$

with $a_t^* = a_t - \rho a_{t-1}$ and $a_i^* = a_i(1-\rho)$.

We estimate this system of equation by GMM (see Blundell and Bond, 1998) using the following orthogonality conditions: $E(\epsilon_{it} \times \triangle\ k_{it-1}) = 0$, $E(\epsilon_{it} \times \triangle\ \pi_{it-1,}) = 0$, $E(\triangle\ \epsilon_{it} \times k_{it-2}) = 0$, $E(\triangle\ \epsilon_{it} \times \pi_{it-2}) = 0$. Essentially these orthogonality conditions state that the fundamental shocks are uncorrelated with past profits and past levels of the capital stock. Our estimate for ρ is 0.47 with a standard error of 0.05. Our estimate for θ is 0.89 with a standard error of 0.15.

3.3 Calculation and Decomposition of the Profit Shocks

In principle one could use the profit and capital stock data to calculate the profit shocks, A_{it} (i.e. by simply using the profit equation $\Pi_{it}/K_{it}^{\theta} = A_{it}$). However, we have noticed that profit series were highly variable, presumably contained measurement error. So we use the following alternative way to determine these shocks. One can show that in our theoretical model profits are equal to a fixed factor times the wage bill:

$$\Pi(A_{it}, K_{it}) = c * w_{it} L_{it}, \tag{14}$$

where c is the fixed factor.

Thus, we can calculate the profit shocks (up to a multiplicative factor) using Equations (10) and (14) as

$$\widehat{A_{it}/c} = w_{it} L_{it} / K_{it}^{\widehat{\theta}}. \tag{15}$$

We then decompose the profit shocks, $\widehat{A_{it}/c}$, into a fixed component and time varying component by regressing the log of the profit shock, $\widehat{A_{it}/c}$, on (a constant and) fixed firm effects.[19] We call the residuals of the regressions $\widetilde{a}_{it}$. They are estimates of the time varying part of the profit shock (in logs): $a_t + a_{it}$. The time varying component, $\widetilde{a}_{it}$, is used in the investment regression.

One can further split $\widetilde{a}_{it}$ to obtain estimates of the aggregate and the idiosyncratic components, respectively a_t and a_{it}, by simply regressing $\widetilde{a}_{it}$ on time dummies. We call these estimates $\widehat{a}_t$ and $\widehat{a}_{it}$. An analysis of variance decomposition into these two components reveals that practically all variation is due to the idiosyncratic time varying component, $\widehat{a}_{it}$.

Table 3. Features of the (Firm Demeaned) Profit Shocks (in logs):$\widetilde{a}_{it}$
min: -0.70
max : 0.78
std. dev. $\widetilde{a}_{it}$:0.16
std. dev. $\widehat{a}_t$: 0.026
autocorrelation $\widetilde{a}_{it}$: 0.48

The dynamics of the estimated idiosyncratic shock obtained from the labor data is consistent with the one obtained from the profit data. The point estimate of the autocorrelation of $\widetilde{a}_{it}$, which is 0.48, is quite close to

[19] Note that one cannot identify the fixed effect from the constant c seperately. However since we are not interested in the level of the parameter A_{it}, but rather in its variation, this distinction is irrelevant for our purposes.

the parameter estimate of the autocorrelation parameter ρ, 0.47, in the GMM system above.

3.4 The Relationship between Investment, Profit Shocks and the Leverage Ratio

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

$$\widetilde{i_{it}} = \psi_0 + \psi_1 \widetilde{i_{it-1}} + \psi_2 \widetilde{a}_{it} + \psi_3 (\widetilde{a}_{it})^2 + \psi_4 (\widetilde{a}_{it-1}) + \psi_5 (\widetilde{\frac{B_{it}}{K_{it}}}) + \psi_6 (\widetilde{a}_{it} \widetilde{\frac{B_{it}}{K_{it}}})^2 + \mu_t + \varepsilon_{it}, \tag{16}$$

where $\widetilde{i_{it}}$ is the deviation of the investment rate at firm i in year t from the firm specific mean, $\widetilde{a_{it}}$ is the demeaned profit shock , $\widetilde{B_{it}/K_{it}}$ is the demeaned leverage ratio, and $(\widetilde{a_{it}}\widetilde{B_{it}/K_{it}})^2$ is the product of both squared. This relationship was suggested by careful examination of the policy function for future capital. Profitability shocks as well as variations 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
$\widetilde{i_{it}}$	0.00	0.13	-0.58	0.63
$\widetilde{i_{it-1}}$	0.00	0.13	-0.53	0.63
$\widetilde{a_{it}}$	0.00	0.14	-0.70	0.63
$(\widetilde{a_{it}})^2$	0.02	0.04	0.00	0.48
$\widetilde{a_{it-1}}$	0.00	0.15	-0.57	0.78
$\widetilde{B_{it}/K_{it}}$	0.00	0.20	-1.24	0.87
$(\widetilde{a_{it}}\widetilde{B_{it}/K_{it}})^2$	0.00	0.001	0.00	0.19

Table 5. Correlation Matrix of the Regression Variables

	$\widetilde{i_{it}}$	$\widetilde{i_{it-1}}$	$\widetilde{a_{it}}$	$(\widetilde{a_{it}})^2$	$\widetilde{a_{it-1}}$	$\widetilde{B_{it}/K_{it}}$	$(\widetilde{a_{it}}\widetilde{B_{it}/K_{it}})^2$
$\widetilde{i_{it}}$	1						
$\widetilde{i_{it-1}}$	0.01	1					
$\widetilde{a_{it}}$	0.48	-0.14	1				
$(\widetilde{a_{it}})^2$	-0.04	0.06	-0.20	1			
$\widetilde{a_{it-1}}$	0.22	0.52	0.48	0.04	1		
$\widetilde{B_{it}/K_{it}}$	-0.27	0.16	-0.36	0.02	-0.16	1	
$(\widetilde{a_{it}}\widetilde{B_{it}/K_{it}})^2$	-0.04	-0.01	0.10	0.50	0.08	-0.15	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 0.48) 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 is 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 profit shock (which implies an

11 percent increase in profits) increases the investment rate during the same year by 6.7 percentage points. The relationship is somewhat nonlinear: 6.1 percentage points is coming from the shock and 0.6 percentage points from the shock squared (The calculation is 0.11*0.557+0.11*0.11*0.531). The reaction of investment to this shock the following year is almost nil (-0.005 = 0.067*0.197+0.11*-0.163). The negative coefficient on the lagged profit shock offsets the positive one on the lagged investment rate.

The negative coefficient on the product between the profit shock and the leverage implies that the effect of a positive profit shock on investment is dampened when a firm has high leverage. For instance, when firm leverage is 1 standard deviation (i.e 0.20) above its mean, the dampening effect is 0.1 percentage points (i.e. ((0.11*0.20)^2)*2.85). Also, independently of the profit shocks, when firms have higher than average leverage, they invest less. A 1 standard deviation higher leverage (i.e 0.20) is associated with an investment rate that is lower than average by 0.02.

Table 6: Auxilliary Regression

	Coefficient
$\widetilde{i_{it-1}}$	0.197* (0.044)
$\widetilde{a_{it}}$	0.557* (0.053)
$(\widetilde{a_{it}})^2$	0.531* (0.155)
$\widetilde{a_{it-1}}$	-0.163*(0.052)
$\widetilde{B_{it}/K_{it}}$	-0.099* (0.029)
$(\widetilde{a_{it}}\widetilde{B_{it}/K_{it}})^2$	-2.85* (0.701)

Note: The independent variable is the investment rate.
Robust standard errors (adj Rsq=0.22). * significant at the 1% level.

3.5 The Transition Matrix of Profit Shocks

For the simulations of the theoretical investment model we represent the aggregate and idiosyncratic components of the profit shocks by first-order

Markov processes. We apply to the estimated profit shocks a discretization method due to Tauchen (1986). Since the standard deviation of the aggregate part is very small (0.026) compared with the standard deviation of the time-varying idiosyncratic part (0.12), we let the aggregate part take on only two values: -0.026 and +0.026 . The probability that the aggregate shock changes state is estimated at 0.26. The transition matrix is given below.

Transition matrix aggregate part of profitability shock

	-0.026	0.026
-0.026	0.74	0.26
0.026	0.26	0.74

For the time-varying idiosyncratic part, a_{it}, we discretize 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 is calculated nonparametrically.

3.6 Structural Estimation

We proceed by fixing *a priori* some of the structural parameters of the model. In particular, we set $r = 0.0413$, $\beta = 1/(1+d)$, $d = 0.0549$, $\delta = 0.085$, $p = 1$, and $\theta = 0.89$. The interest rate r has two functions in our model. First, it is the renumeration interest rate for the firm if it has negative debt , i.e. if it accumulates funds. Second, it is the lowest marginal interest rate at which the firm can borrow if it has zero debt. It is set at 4.13 percent which is the average real yield on industry bonds in Germany over the period 1966-2002. The marginal interest rate for firms with positive debt is $r+\ \alpha\frac{B_{it}}{pK_{it}} + r\alpha\frac{B_{it}}{pK_{it}}$. The discount rate is set at 5.49 percent. It is the average real yield on German stocks (measured by the DAX index) over the period 1966-2002. Setting the discount rate d higher than r ensures that a firm has an incentive to make dividend payments and not accumulate an infinite amount of assets.

Suppose that a firm makes positive profits, has no debt and has enough funds for investment. If $r > d$, the firm simply accumulates funds and never pays them out. Note that if such a firm would never face negative shocks, it would have an infinite value since the rate at which assets would accumulate, r, would be larger than the discount rate. Since we impose $d > r$, the firm has an incentive to take positive debt to finance itself. Only by taking positive debt can the firm equate the discount rate with the marginal cost of debt finance.

The depreciation rate is based on our estimates with data from German manufacturing industry and is described in the Appendix. The profitability curvature parameter, θ, was estimated from our data as explained in Section 3.2. The vector of remaining structural parameters to be estimated is called $\Theta \equiv (\alpha, \gamma, F)$. We will estimate them using the indirect inference method.[20] This approach involves several well-defined steps.

First, we solve the firm's dynamic programming problem for arbitrary values of the structural parameters, Θ, and generate the corresponding optimal policy functions.[21] Second, we use these policy functions and arbitrary initial conditions to generate simulated data. In particular, we generate 14 artificial panels each containing data for 170 firms for 7 years.[22] Third, this simulated

[20]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 (2003) estimate an investment model with both convex and non-convex adjustment costs. Adda and Cooper (2000) study the impact of scrapping subsidies on new car purchases. The distribution of price adjustment costs are estimated by Willis (1999). Cooper and Ejarque (2003*a* and 2003*b*) investigate the role of market power in the Q theory.

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

[22]We drop observations corresponding to initial periods in order to purge dependence on initial conditions.

data set is used to calculate the model analogues of the auxilliary regression coefficients and moments we obtained using actual data.[23] We have chosen to match the coefficients, ψ_1 through ψ_6, of the auxilliary regression (16) together with two moments: the standard deviation, ψ_7 , and autocorrelation, ψ_8, of (demeaned) investment rates.

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, is arbitrarily close. If they are not, Θ is updated 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:

$$\min_{\Theta} J(\Theta) = (\Psi^d - \Psi^s(\Theta))' W (\Psi^d - \Psi^s(\Theta)), \tag{17}$$

where W is a weighting matrix.[24] In practice, we use the method of simulated annealing in order to minimize $J(\Theta)$.[25]

3.7 Results

The point estimates of the structural parameters are given in Table 7. The parameter α determines the external finance premium. An increase of the

[23]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.

[24]We use the identity matrix, which provides consistent estimates.

[25]There are a couple of advantages of this method compared to the conventional algorithms. First, this method explores the function's entire surface. Thus it is almost independent of starting values. The other advantage of this method is that it can escape from local optima. Further, the assumptions regarding functional forms are not strict. Goffe, Ferrier, and Rogers (1994) provide evidence that this algorithm is quite good in finding the global optimum for difficult functions.

leverage ratio of 1 standard deviation, i.e. by 20 percentage points increases the external finance premium by 0.25 percentage points (i.e. 25 basis points). Recalling that the baseline lending rate is 413 basis points, we have a 6 percent increase in the interest rate. Thus, the estimated impact of financial frictions on investment is relatively modest.

Table 7. Estimates of the Structural Parameters

Parameter	Estimate	Standard error
α	0.012	0.0013
γ	0.532	0.0726
F	0.031	0.0012

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: $C(K_{it}, I_{it})/K_{it} = p\frac{I_{it}}{K_{it}} + \frac{\gamma}{2}\left[\frac{I_{it}}{K_{it}}\right]^2 + F$. At the mean investment rate of 0.19 the convex adjustment cost, $\frac{\gamma}{2}\left[\frac{I_{it}}{K_{it}}\right]^2$, is 0.009, the fixed cost, F, is 0.031. In other words, when the investment rate is 0.19, total convex adjustment costs are 4.7 percent (or 0.009/0.19) of the purchase cost, and total fixed adjustment costs are 16.3 percent of the purchase cost of investing (0.031/0.19). Thus, it seems that fixed costs of adjustment are quantitatively more important than convex ones. The fraction of total investment cost that is due to real frictions in adjusting capital is 17.4 percent ((4.7+16.3)/(1+(4.7+16.3)). This is substantial though not excessive. It is of interest to compare our estimates of γ and F to those of Cooper and Haltiwanger (2003): $\gamma = 0.049$ and $F = 0.039$. The latter estimates a lower relative importance of convex adjustment costs. It is likely that this arises from the level of aggregation of the data used: plant level in Cooper and Haltiwanger (2003) versus firm level in our paper. Alternatively, it may result from differences in specification.

Table 8 shows the coefficients of the auxilliary regression and the two moments using the actual data and the simulated data (where the simulated data were obtained using the structural parameters as in Table 7). In general the match is quite good with the exception of the serial correlation in investment (reflected also in the coefficient of lagged investment in the auxilliary regression).

Table 8. Auxilliary Regression Coefficients and Moments: Actual versus Simulated Data

Coefficient	Data	Std. error	Model	Std.error	Difference
$\widetilde{i_{it-1}}$	0.197	(0.044)	0.036	(0.008)	0.161
$\widetilde{a_{it}}$	0.557	(0.053)	0.369	(0.007)	0.188
$(\widetilde{a_{it}})^2$	0.531	(0.155)	0.470	(0.025)	0.061
$\widetilde{a_{it-1}}$	-0.162	(0.051)	-0.212	(0.007)	0.050
$\widetilde{B_{it}/K_{it}}$	-0.099	(0.029)	-0.183	(0.006)	0.084
$(\widetilde{a_{it}B_{it}/K_{it}})^2$	-2.847	(0.701)	-2.817	(0.314)	-0.030
Moments	Data		Model		
$\text{corr}(\widetilde{i_{it}}, \widetilde{i_{it-1}})$	0.008		-0.095		0.103
$\text{std}(\widetilde{i_{it}})$	0.139		0.145		-0.006

Gourieroux, Monfort, and Renault (1993) suggest a global specification test for indirect estimation models based on the optimal value of the objective function, which corresponds to Equation (17) in this paper. The statistics for the specification test is:

$$\xi_T = \frac{TH}{1+H} \min_{\Theta} \ (\Psi^d - \Psi^s(\Theta))' W (\Psi^d - \Psi^s(\Theta)).$$

where H is the number of artificial panels, T is the number of years. It is asymptotically distributed as a chi-square with q – p degrees of freedom, where q is the dimension of moments and p is the dimension of structural parameters. In our case, H = 14, T = 7, q = 8, and p = 3. The structural parameters given in Table 7 produce $\min_{\Theta} \ (\Psi^d - \Psi^s(\Theta))' W (\Psi^d - \Psi^s(\Theta)) =$ 0.086. Thus, the test statistics is equal to 0.562, which indicates that over-identifying restrictions are not rejected.

Another way to evaluate the estimated structural model is to see how well it performs in moments that were not attempted to be matched in estimation. Table 9 shows some alternative moments for the actual and simulated data. The model captures well the contemporaneous correlation of the profit shock with the investment rate. The simulated data display a substantial fraction of investment spikes though a bit lower than in the data. The correlation between investment and debt leverage as well as the serial correlation in leverage are matched quite well.[26] However, the model has problems reproducing the negative contemporaneous correlation between the profit shock and the leverage ratio.

Table 9. Comparing Moments

	Data	Model
corr($\widetilde{a_{it}}, \widetilde{i_{it}}$)	0.48	0.30
$I_{it}/K_{it-1} > 0.20$	0.38	0.27
corr($\widetilde{a_{it}}, \widetilde{B_{it}/K_{it}}$)	-0.36	0.05
corr($\widetilde{i_{it}}, \widetilde{B_{it}/K_{it}}$)	-0.27	-0.24
corr($\widetilde{B_{it}/K_{it}}$, $\widetilde{B_{it-1}/K_{it-1}}$)	0.42	0.71

4 Conclusion

In this paper we explore the interaction between finance and investment at the firm level. Our key contribution is to move beyond simply testing and rejecting a neoclassical model with convex adjustment costs. Instead, we propose and estimate a specific model of investment with costly external finance and both convex and non-convex adjustment costs.

[26] Note that when setting the financing premium equal to zero (i.e. alpha=0) in the model, the correlation between investment and debt leverage reduces to -0.20. A negative correlation between debt leverage and investment is therefore not a sufficient condition for the existence of external finance premia.

Our quantitative estimates show that both real and financial frictions are important in determining firm investment dynamics. However, at least for our sample of large German manufacturing firms, the impact of external finance constraints on investment is relatively modest. Regarding real frictions, the major component of adjustment costs seems to be fixed.

A APPENDIX

A.1 Sample Selection

The major data source is the AMADEUS database from Bureau Van Dijk (releases CD-rom June 2001 and September 1997). This is a database including firm balance sheet, and profit and loss information for more than 30 European countries. We only use the information on German firms. Our analysis is concentrated on the largest German manufacturing firms over the period 1992-1999.[27]

The elimination of the firms is conducted in a number of steps.

1. We use only consolidated accounts. This means that data are all on the group level (capital stock, assets, turnover, etc.) There are 1334 firms (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 firm. It is customary that the output of a large firm 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, while its unconsolidated turnover is around 11 billion euro. Second, the true financial boundaries of the firms are the group, not the individual plants. For instance for investment purposes, cash flow 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,

[27] Most German firms have only minor legal obligations to provide accounting information. Thus we excluded the firms which did not report their capital stock information. For instance, the June 2001 CD-rom contains accounting information on 39,965 firms (both manufacturing and non-manufacturing firms), however 32,832 have only limited accounting information. In general these firms are relatively small or subsidiaries of larger firms.

which contains consolidated data.

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

3. We only keep firms if they have information on profits and cash flow. This leads to 170 firms.

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 measuring a merger or acquisition. So 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 firm could change substantially as a result of any merger or acquisition activities. This leads to our final dataset of 170 firms on 1163 observations. The dataset is unbalanced. However, each firm has at least 3 observations. On average, a firm has 6.8 observations. The maximum number of observations for a firm is 8.

These 170 firms are truly the largest ones. The total replacement value of their capital stock was 101 billion euro in 1995, while the total manufacturing industry in Germany had the capital stock of 483 billion euro.

A.2 Description of the Variables

A.2.1 Raw Variables from the CD-rom

FIAS: Fixed assets; represent the book value of all fixed assets of the firm, including building and structures, machinery and equipment, intangible fixed assets, and financial fixed assets (share ownership in other companies)

OFAS: other fixed assets, mainly financial fixed assets

OPPL: operating profit or loss

DEPR: depreciation

PL: profit or loss of the year; operating profits after exceptional items, taxation and interest payments

STAF: wage bill of the firm

A.2.2 Constructed Variables

Book value capital stock, K_t^b : constructed by the calculation FIAS-OFAS.

Investment price deflator, P_t^I*:* constructed by dividing aggregate industry investment data in current by prices of 1995.

Investment at current prices, I_t^c : The AMADEUS database does not give gross investment figures 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 : constructed as investment at current prices deflated by the investment price deflator I_t^c/P_t^I.

Real capital stock, K_t*:* constructed using the perpetual inventory method. The book value of the first year was multiplied by a factor $1.26/P_t^I$ to convert the book value into the 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 industry level data. The depreciation rates are between 6 and 13 percent.

The average depreciation rate is 8.5 percent. The perpetual inventory formula is $K_t = (1-\delta)K_{t-1} + I_t$

Investment rate, $\frac{I_t}{K_{t-1}}$*:* constructed by dividing I_t by K_{t-1}.

Real profits, π_t*:* constructed as operating profits plus depreciation (OPPL+DEPR) deflated by the German GDP deflator.

Real cash flow, CF_{it}*:* constructed as profits or loss plus depreciation (PL+DEPR) deflated by the German GDP deflator.

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