WISSENSCHAFTSZENTRUM BERLIN
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discussion papers

FS IV 97 - 45

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Dietmar Harhoff

December 1997

ISSN Nr. 0722 - 6748

Forschungsschwerpunkt Marktprozeß und Unternehmensentwicklung

Research Area Market Processes and Corporate Development

Zitierweise/Citation:

Dietmar Harhoff, **Are There Financing Constraints for R&D and Investment in German Manufacturing Firms?** Discussion Paper FS IV 97 - 45, Wissenschaftszentrum Berlin, 1997.

Wissenschaftszentrum Berlin für Sozialforschung gGmbH,
Reichpietschufer 50, 10785 Berlin, Tel. (030) 2 54 91 - 0

ABSTRACT

Are There Financing Constraints for R&D and Investment in German Manufacturing Firms?

Dietmar Harhoff*

Using a newly constructed panel dataset of German enterprises, I estimate R&D and capital investment equations for the time period from 1990 to 1994. Simple accelerator specifications indicate considerable sensitivity of R&D and investment to cash flow for relatively small firms. Much of this effect vanishes already once error-correcting behavior is taken into account, but a significant positive relationship between cash flow and investment remains for relatively small firms. In the case of R&D, weak but significant cash flow persist both for small and large firms. The evidence from Euler equation estimates is not conclusive. The investment Euler equation for large firms appears to perform relatively well and yields results close to those expected under the null hypothesis of no financing constraints. The estimates from the Euler equation for R&D are not informative. Additional evidence from survey data suggests that the cash flow sensitivity of investment in small firms is likely to reflect financing constraints.

* This research has been supported by grants from the German Research Council (DFG) and the ZEW. I would like to thank conference and seminar audiences in Bonn, Strasbourg, Konstanz, Mannheim, at the NBER Summer Institute, the Wissenschaftszentrum Berlin, the EEA meeting in Istanbul, and a DFG workshop in Heidelberg for helpful comments. I am grateful to Wesley Cohen, Christian Dustmann, Zvi Griliches, Martin Hellwig, Bronwyn Hall, Olaf Hübler, Tor Jacob Klette, Jan Pieter Krahnen, Dennis Mueller, Ishaq Nadiri, Manfred Neumann, and Lars-Hendrik Röller for their helpful suggestions. Steve Bond and John Van Reenen were particularly supportive in discussing this work. I also acknowledge insightful and detailed comments made by two anonymous referees and the editor, Francois Laisney. The construction of the database has been competently performed and supported by Christiane Bühler, Marc Dehoust, Andreas Fier, Urs Finger, Lydia Irrgang, Oliver Schmale, and Julia Wienbeck. All remaining errors are my responsibility.

1 Introduction

This paper is concerned with an aspect of firm behavior that has only recently reemerged as a central problem in corporate finance and industrial organization - the potential existence of financing constraints and their implications for investment and innovation at the firm and the aggregate level. As early as in the Sixties, a number of researchers (e.g., Meyer and Kuh (1957), Duesenberry (1958), Meyer and Glauber (1964)) had proposed informal theories of liquidity and investment and had tried to test these models empirically. But the notion of financing constraints did not receive major support among economists until highly influential papers by Jaffee and Russell (1976), Keeton (1979), and Stiglitz and Weiss (1981) pointed to possible equilibrium credit rationing by lenders. The key assumption driving the results of these papers concerns asymmetric information between borrower and lender. Papers by Myers and Majluff (1984) and Myers (1977, 1984) also suggested a causal relationship between asymmetric information and the firm's preference for internal finance.

The paper by Fazzari, Hubbard, and Petersen (1988) has been the first empirical study explicitly building on these theoretical contributions. Since then, there has been a large number of empirical investigations in this field, mostly focusing on financing constraints for capital investment. The overall picture is still clouded by difficult econometric and conceptual problems. In a recent debate, some doubts have been expressed that the cash flow effects detected by these studies can be interpreted as evidence of financing constraints (Kaplan and Zingales 1997). In any case, it has been difficult to quantify the extent of these constraints precisely, or to assess their interaction with the institutional framework, e.g. the role of intermediaries in general and of banks in particular. Therefore it is still difficult to gauge the overall economic implications of financing constraints in a reliable manner.

Investment in capital goods may not be the only firm activity where financing constraints can be of importance. Actually, since investments in intangible assets (like know-how or consumer goodwill) are presumably more risky and provide less collateral to lenders than capital goods do, liquidity effects might be even more pronounced for these activities. Grabowski (1968) provided some early cross-sectional support for this view, while Mueller (1967) and Hamburg (1966) did not find such an effect. In more recent work, Bernstein and Nadiri (1986), Hall (1992), Hao and Jaffe (1993), Himmelberg and Petersen (1994), and Kathuria and Mueller (1995) have produced evidence that liquidity effects may also be at work in determining R&D activities. But the evidence on this point is still very tentative and warrants further attention, given that R&D is already subject to a number of externalities which may lead to under-investment in a market economy.

Due to data constraints, the empirical evidence for Germany has been particularly scarce. A few studies have analyzed the financing aspects of capital investment in Germany

(Elston 1995, Elston and Albach 1994, Audretsch and Elston 1994). These investigations have been based on the *Bonn Database* which contains comprehensive data on publicly traded German enterprises. These studies have pointed to the existence of cash flow effects for the investment activities of even the largest enterprises, but have so far excluded the firm's innovation activities. Moreover, only the investment behavior of publicly traded firms has been analyzed so far. This may not be a serious problem in the United States where a relatively large number of small and medium-sized firms have access to equities markets. It is definitely a concern in Germany where access to the stock market is tight and market capitalization is relatively low. The prominent role that small and medium-sized firms take in the German economy makes a study of their investment and R&D behavior an appealing exercise.

The purpose of this paper is to provide an analysis of the relationship between finance and investment behavior using a new dataset describing the R&D and investment decisions of German firms, including independent medium-sized enterprises whose shares are not traded in the stock market. In the first part of the empirical exercise, I estimate accelerator and error-correction models for investment and R&D. The cash flow effects obtained from these regressions cannot be interpreted without ambiguity. In particular, cash flow may also be correlated with investment opportunities.[1] It is nonetheless instructive to study the variation of these coefficients across firms of different size. Below I present results which suggest that the investment policies of smaller firms are indeed more sensitive to cash flow variations than those of relatively large firms. In order to test whether these results from accelerator and error-correction models point to the existence of financial constraints, I also implement structural Euler equation models for investment and R&D, but the results are unfortunately not satisfactory. What remains in terms of results is evidence of size-contingent cash flow effects for investment and R&D. Additional evidence from other data sources suggests that this effect actually mirrors financing constraints at the firm level.

The paper proceeds as follows. Theoretical aspects and some previous empirical results will be summarized briefly in section 2. In section 3, I describe the data used in this study and central descriptive statistics. Three econometric specifications are discussed briefly in section 4, and estimation results are presented in section 5. The central results are based on accelerator and error-correction specifications, but I also derive and estimate Euler

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[1] The interpretation of cash flow as an indicator of investment oppotunities is not the only alternative explanation at hand. As Jensen (1985) has argued, managers may have incentives to let firms grow beyond optimal size. Cash flow in excess of what is needed to fund the optimal level of investment will then not be turned over to share-holders, but managers will invest at below the cost of capital. In such a case, externally imposed financing constraints may actually have positive implications in that they prevent management from making such investments. The Jensen hypothesis is clearly a serious contender in interpreting what the implications of financing constraints will be. But the paper presented here will - for now - merely attempt to explore whether there is reason to believe that such constraints exist.

equations for R&D and investment. The final section summarizes the results and concludes with a number of suggestions for further work.

2 Theoretical Aspects and Previous Studies

2.1 Asymmetric Information, Credit Rationing and Financing Hierarchies

Credit markets are different from standard commodity markets in that the lender delivers a loan on the borrower's promise to pay back the loan and interest. The lender's evaluation of the borrower's capability to pay back is crucial for the lending decision.[2] Equilibrium quantity rationing thus emerges endogenously due to asymmetric information (the lender knows less about the borrower than the borrower herself) and incompleteness of contracts (contractual agreements to control all aspects of borrower behavior are infeasible). In the case of rationing, the lender will decide not to grant a loan to the borrower, even if the borrower offers a higher interest rate than is observed in the market for loans. Thus, the supply of loans does not equate the demand at the market interest rate.

The underlying logic for all credit rationing phenomena are the self-selection and incentive effects imposed by interest rates. Adverse selection occurs, since the average quality of borrowers will be a decreasing function of the interest rate charged by the lender. Moreover, as the interest rate increases the borrower will be tempted to undertake riskier projects unless the loan is fully collateralized. In this context, there may exist an interest rate that maximizes the lender's profit although supply does not equal demand. Either some lenders are not able to obtain any loan, or the loan size will be below the one demanded by the borrower (Bester and Hellwig 1987).

Asymmetric information may also lead managers not to issue new equity. In an influential paper, Myers and Majluf (1984) analyze the effect of asymmetric information if managers have privileged knowledge about the true value of investment projects and the firm's other assets while investors (or lenders) only know the joint distribution of these values until the ex ante random characteristics of the projects are revealed. Managers are assumed to act on behalf of existing shareholders. Managers will issue new shares only if this is not to the disadvantage of existing stockholders, i.e. if the market's evaluation of the new stock is above the respective value for the existing stockholders. Thus, managers will only issue shares for investments with less than expected value. Consequently, issuing shares will be seen by the new investors as a bad signal. Anticipating this, the firm

[2] For surveys, see Clemenz (1986), Baltensperger and Devinney (1985), and Bester and Hellwig (1987).

will not issue new shares even if the projects have positive net present value. Thus, financing constraints have negative welfare effects in this model.[3]

The conclusions that can be derived from the Myers/Majluf and other models are quite strong. Given that management acts in the interest of existing shareholders, firms will prefer internal finance over debt financing, and debt financing over the issuance of new shares. Furthermore, issuing new shares will typically lead to a decline in the stock price. Both predictions have found some empirical support.[4] As a result of some of these arguments, Myers and Majluf (1984), *inter alia*, have postulated a financial "pecking order" model which deviates considerably from either the static equity-debt tradeoff model or the ranking of capital costs suggested by Auerbach (1983). Once slack resources are exhausted, the firm will have to borrow to satisfy its capital needs. The most expensive type of capital will be new equity. In some cases, the firm will rather forego an investment opportunity than to issue debt. Variations in cash flow will lead to more investment in such a situation. Note that in the pecking order model, there is no well-defined optimal capital structure as it exists in the static Modigliani-Miller model with taxation. The model developed by Myers and Majluf does not directly relate long-term capital structure, but the availability of slack resources to investment spending. Indirectly, though, the model suggests a motive for precautionary corporate saving ("cash stock-piling").

In another paper, Myers (1977) also comments on the relationship between capital structure and the nature of the firm's projects. Suppose that the true value of the firm is given by the value of its assets in place and the value of future investment opportunities. The extent to which the latter can be exploited depends on discretionary spending by the firm's management. In essence these opportunities represent call options. Suppose that the firm issues risky debt to finance such an investment opportunity. The existence of risky debt introduces a wedge between the firm's marginal value and the marginal value of equity. On average, this will lead to underinvestment. The stock market's evaluation of the prospective behavior of the shareholders will lead to an ex ante reduction of the value of the firm. Moreover, lending may be rationed in this context. To rational lenders and equity owners the value of a firm with relatively important growth opportunities will decline with leverage. Myers concludes that the more the firm's value is determined by future investment opportunities relative to assets in place, the more it will favor equity financing in order to avoid the underinvestment effect. In empirical terms, this theory suggests that innovative firms with few assets already in place (say small companies with a promising new product, but no established products) should be mostly equity-financed.

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[3] Variations of the fundamental theme of the Myers/Majluf paper have been developed in large numbers, but the basic idea is the same in these extensions. For example, Krasker (1986), Besanko and Thakor (1987), Thakor (1993).

[4] See the review of empirical evidence in Thakor (1993, p. 461).

It is beyond the scope of this paper to test this theory thoroughly, but it is an interesting question to be pursued in future work.

2.2 Different Types of Investment: Capital Goods versus Know-How

It is by now generally acknowledged that externalities in the form of information or knowledge „spillovers“ play a potentially important role in shaping the incentives for research and development activities (R&D) of private firms. Much less is known about the potential effects of financing constraints on innovation. Can liquidity constraints - if they exist - be particularly important for investments in research and development (R&D) or innovation projects? The literature lists a number of reasons why investment in physical capital and investment in knowledge capital should be affected differently by financing constraints, and why obtaining external finance for innovation and R&D projects may be more costly than obtaining such funding for capital investment. At the same time, fundamental technological differences with respect to the adjustment costs of investment and R&D may work against pronounced sensitivity of R&D spending to transitory shocks in cash flow.

As Hall (1992) points out, contrary to most capital investment goods (plant, property, and equipment), R&D results such as a new prototype or a design cannot be used easily as collateral. The investment share of R&D expenditures is on the order of ten per cent of total R&D expenditures, and most inputs to the innovation process are likely to be firm-specific or specific to the new product or process to be developed. Thus, an external financier cannot expect to recover a significant share of her funds if it is used to finance an innovation project.

Second, for obvious reasons firms are unlikely to reveal content and objectives of their R&D efforts, since this knowledge may leak out to competitors.[5] Strategic considerations of this kind will tend to maintain and reinforce informational asymmetries. But even without secrecy undermining the incentives to share information about R&D projects, the evaluation of long-term risky projects by external financiers may be more costly than the assessment of more short-term oriented ones. Thus, if providers of finance face greater uncertainty with respect to R&D than to investment projects, they will require a higher lemon’s premium for the former type of investment. Hence, even without rationing behavior on behalf of banks and other financial institutions, there will be a premium to be paid for obtaining external funding. This is of course the classical argument that leads Myers and Majluff (1984) to postulating a financial hierarchy in

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5 See Mansfield (1985) for some evidence on the speed of information dissemination. Theoretical models of knowledge dissemination are presented by Bhattacharya and Ritter (1985) and Bhattacharya and Chiesa (1994).

which internal funds are the cheapest source of capital. If lenders cannot control which kind of project will be financed by the loan, then the cost of capital will reflect the financiers' assessment of average project risk.

While the above arguments may suggest that R&D will be more susceptible to cash flow variations, there are other considerations that work in the opposite direction. It is likely that the R&D process cannot be delayed or accelerated to the extent to which this may be possible for capital investment. Scientists cannot be fired and rehired without substantial loss of human capital to the firm (and potential gains to competitors), and due to their high degree of specialization, resources employed in R&D cannot simply be used in production (or vice versa). Thus, adjustment costs are likely to be higher for R&D than for investment. We would expect to see relatively high persistence in R&D data - an expectation that is indeed born out by the empirical evidence (e.g., Lach and Schankerman 1989). Moreover, this effect will actually dampen the long-term response of R&D to cash flow variation.

However, the extent of adjustment costs may well be a function of the type of projects undertaken - and thus a choice variable for firm managers. If a firm anticipates that its cash flow may be highly fluctuating and that external finance will not be available to fund R&D projects, then the respective R&D budget may favor projects that have a relatively short duration or are relatively flexible in terms of adjustment opportunities. One branch of the theoretical literature has considered the effect of different project duration for investor response and managerial choices. Shleifer and Vishny (1990) show that if long-term projects stay mis-priced for a longer period than projects with short duration, then managers may select short-term projects. Thakor (1993) distinguishes between „late bloomer" projects (high payoff in the more distant future) and „early winners" (projects with lower returns in the near future). If managers care about existing stockholders, then the stock price reaction to an equity issue for a „late bloomer" project will be negative while it might be positive for the other type of project. R&D projects are - when compared to investment projects - such late bloomers (Thakor 1993). But R&D itself may be heterogeneous, and managers may be able to choose short-term R&D projects over ultimately more profitable long-term ones if financing constraints are anticipated. A sequence of short-term projects can be adjusted far more easier than long-term projects which cannot be accelerated or slowed down without some penalty.

As mentioned before, there are only few studies to date that have analyzed the potential impact of financing constraints on the firm's innovation policy. Hall (1992) finds that the elasticity of investment and R&D with respect to cash flow is positive and significant in a large sample of U.S. manufacturing firms. Interestingly, the results suggest that the effect on investment is stronger than the effect on R&D. She computes long-term cash flow elasticity values of 0.46 for investment and 0.28 for R&D spending. Himmelberg and Petersen (1994) present an investigation of the effect of financing constraints on relatively small U.S. firms in high-technology industries. The elasticities (at the sample mean) implied by their estimates are noteworthy: in the case of investment, Himmelberg and Petersen calculate a cash flow elasticity of 0.83. For R&D, the elasticity is on the order of 0.36. Investment in these companies appears to react to transitory movements in cash flow, while R&D expenditures are being smoothed according to the permanent component of cash flow. Himmelberg and Petersen argue that firms face relatively large adjustment costs in their R&D activities and cannot adjust the intensity of these efforts to short-term liquidity shocks. As argued before, these results are subject to the critique that cash flow effects cannot be interpreted unambiguously as indicators of financial constraints.

2.3 Firm Size and Financing Opportunities

Firm size plays a central role in this study. I argue in this paper that small firms are more likely to be characterized by excess sensitivity to the availability of internal finance.[6] First, smaller firms will be characterized by idiosyncratic risk which would raise the cost of external capital. In addition, a randomly chosen group of small firms will include a relatively large number of young firms, hence outside investors may not yet have sufficient information to distinguish good from bad performers. Second, these firms may also have more limited access to external financial markets, in particular in Germany where access to the stock market is limited. Third, these firms have less collateral (in terms of existing assets) which could be used for obtaining external loans. Moreover, smaller firms may employ more flexibly adjustable R&D and investment processes than large firms do. Thus, the response to liquidity effects should be faster, i.e. the respective processes should display less persistence, even after accounting for presumably larger fluctuations in sales or other determinants of investment.

While there is a considerable number of studies looking at the relationship between investment, finance and firm size[7] only very little evidence is available on the impact of firm size on the finance-R&D relationship. Hao and Jaffe (1993) find evidence that small firms' R&D expenditures react more strongly to measures of cash flow or working capital than R&D performed by larger enterprises. However, they do not compare R&D and investment behavior, and their empirical test does not take adjustment processes into account. Winker (1996) uses managerial survey responses as indicators of financial constraints. He finds that managers are more likely to indicate that their firms are financially constrained if the respective firm is small, and if demand expectations are

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6 These arguments are neither new nor original. See, for example, Schiantarelli (1995, pp. 31-33) and the references cited therein.

7 See Schiantarelli (1995) for a summary of results.

positive. In regressions using investment and innovation expenditures as the dependent variables, the financial constraints variables yield a significant negative effect.

3 Data Source and Descriptive Statistics

3.1 Data Sources and Data Collection

Data on R&D expenditures at the firm level are difficult to obtain in Germany. In previous work, I used the most comprehensive database - provided by the Stifterverband für die Deutsche Wissenschaft - to study productivity and spillover effects (Harhoff 1996, 1997). Containing detailed information on the firm's R&D expenditures and their breakdown, those data do unfortunately not contain information on the financial performance of firms. For the purpose of this study, an entirely new panel dataset was constructed from publicly available sources and complemented - if necessary - with confidential data from the Mannheim Innovation Panel. The most important public source for R&D information were financial statements, published in the *Bundesanzeiger*. In some cases additional data were obtained from yearly business reports. The final dataset is an unbalanced panel of 236 German firms and covers the period from 1987 to 1994. Due to the recession of the German economy following the reunification boom, the data span a period that is characterized by rather divergent business conditions and considerable changes in firms' liquidity.

Details regarding sample composition, variable definitions and other important aspects of „data cleaning“ are relegated in the data appendix. Due to a number of exclusion restrictions, the initial sample of about 2300 observations of R&D expenditure data shrinks to a sample of 1755 observations and 299 firms. Applying the constraint that at least three consecutive observations have to exist on all relevant variables and using „cleaning“ procedures described in the appendix, we have finally a sample of 1365 observations for 236 firms. There are seven or eight observations for 90 firms; another 86 firms have either 5 or 6 observations; and 60 firms have either 3 or 4 observations. The sectoral composition of the panel is described in Table 1. It reflects the particular specialization of German industry in the production of chemicals and pharmaceuticals, machinery, and electrical products quite well - 161 of the total of 236 firms are operating in these sectors.

3.2 Descriptive Statistics

This paragraph briefly describes the sample in terms of its properties and descriptive statistics. A number of points need to be stated at the outset. First, the sample is not representative. Quite to the contrary, it has emerged from a complex selection process. Moreover, German corporate law gives firms some leeway in choosing how to comment on their R&D activities. The reporting may range from precise data on expenditures, R&D personnel and patenting activity to simple comments like „R&D was performed." Only firms with information that would allow the computation of R&D expenditures are included in the sample. Nonetheless, due to the inclusion of large enterprises, the sample captures in each of the years from 1987 to 1994 slightly more than 50 percent of private R&D spending in the Federal Republic. This is not surprising, given the concentration of R&D spending in large firms.

Table 2 presents means, medians and the interquartile ranges of the most important variables. Most distributions are highly skewed due to the presence of very large enterprises. At the median of the 1990 sample, firms have sales of about DM 445 million (in 1985 prices). The size distribution thus seriously restricts the possibility of analyzing financing problems of small firms. The empirical strategy to do so with this sample relies on splitting the sample at the median of the initial year sales distribution. The lower quartile of the 1990 sales distribution for smaller firms is at DM 95 million, the upper quartile at DM 260 million.

The overall sample is also fairly research-intensive. The mean of R&D intensity (real R&D expenditures divided by real sales) is 5.1 percent. This is considerably above the average R&D intensity among German R&D-performing firms which is on the order of 2.2 percent. Figure 1 plots the R&D intensity distribution of all firms with data for 1990. The shape of the distribution conforms to the plots presented by Cohen and Klepper (1992) for the United States: it is roughly unimodal and skewed to the left.

The firm's willingness to reveal its R&D expenditures in a consistent way may be correlated with the firm's size and the extent of innovation in the industry. For small, specialized firms any revelation of the extent of innovation may generate information for competitors that may be deemed harmful by the firm's management, thus leading to a preference for secrecy. As to the above-average R&D intensity, it is well-known that pharmaceutical and chemical companies have published R&D-related data for some decades. In some industries, the signalling value of revealing the firm's R&D expenditures may be significant. As Table 1 shows, the dominant industries in the sample used here are indeed chemicals and pharmaceuticals, electrical products, and machinery. Simple productivity regressions also show that the elasticity of revenues with respect to the R&D capital stock is on the order of 10 percent in fixed-effects estimates. This result is consistent with elasticities computed for a panel of firms in high-technology industries in the Stifterverband data (Harhoff 1997, Table 4). Table 2 suggests that the sample firms spend on average slightly less on R&D than on investment. In conclusion, R&D is an important activity for the firms in this sample.

The key feature of the dataset is the linking of financial performance data with R&D and investment expenditure information. Partial correlation coefficients can be used to establish a number of stylized facts. In simple OLS regressions using R&D scaled over capital as the dependent variable and including time dummies, firm size, and revenue growth among the right-hand side variables, the coefficient (standard error) of cash flow is 0.45 (0.012). Using investment over capital as the dependent variable, the respective cash flow coefficient (standard error) is given by 0.12 (0.011). Including detailed industry dummy variables at the two-digit SYPRO level does not change these results by much. Thus, after controlling for observable firm characteristics, the cross-sectional relationship between cash flow and R&D is much stronger than between cash flow and investment in tangible capital.

A causal interpretation of this correlation is obviously subject to a number of problems. First, the OLS estimates completely neglect the possibility that firm-specific effects can render the estimated coefficients inconsistent. For example, the relationship between cash flow and R&D may be spurious, since profitability (and thus cash flow) may simply be correlated with the extent of firm-specific technological opportunities, and therefore with the firm's propensity to invest in R&D. Second, since the symmetric treatment of R&D and investment requires a correction of the cash flow variable (R&D has been expensed and must be added back to cash flow), measurement error in the R&D variable will lead to a positive, but meaningless correlation. These complications will be addressed below in more refined dynamic specifications.

As pointed out in the previous section, it would be interesting to compare the capital structure of firms with respect to the kind of investments undertaken by these enterprises. Most of the theoretical arguments presented in section 2 imply that debt finance is not conducive to R&D spending. To explore the relationship between capital structure and the firm's investment policy, the correlation between debt and R&D spending (or R&D capital stock) can be analyzed. This has not been undertaken in a systematic way in this project, but preliminary results indicate that the correlation between R&D activity (measured as the ratio of R&D capital over the sum of R&D capital and physical capital) and the firm's longterm debt (measured as longterm debt divided by the sum of R&D capital and physical capital) is consistently negative in all years. The respective correlation coefficients appear to range between -0.05 and -0.15 and are thus weaker than the negative correlations found in US data by Hall (1992) which were on the order of -0.2 to -0.3.[8] A more detailed analysis of the link between capital structure and innovation in this sample is left to a separate study.

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[8] The results are preliminary, since the balance sheet data used so far are too coarse to adjust the debt variable for reserve holdings for pensions. Such a correction is currently under way.

4 Econometric Specifications for Investment and R&D Spending

This section briefly describes the econometric framework used in the analysis. While cash flow-investment elasticities are ambiguous, non-structural models like accelerator (section 4.1) or error-correction specifications (section 4.2) are nonetheless informative starting points. Clearer evidence should in principle come from a structural Euler equation model introduced in section 4.3.

4.1 Accelerator Models

Investment accelerator specifications have been used, *inter alia*, by Bond et al. (1994). The derivation of such a model follows the usual logic which postulates a relationship between the logarithm of output $y_{i,t}$, the logarithm of the desired stock of capital $c_{i,t}$, and the user cost of capital $j_{i,t}$

(1) $$c_{i,t} = a + y_{i,t} - \sigma\, j_{i,t}\,.$$

This model can be derived from a profit maximization problem, given a CES production function with elasticity of substition σ. By taking first differences and applying the usual approximation $D c_{i,t} \approx I_{i,t} / K_{i,t-1} - \delta$ one arrives at

(2) $$\frac{I_{i,t}}{C_{i,t-1}} = \delta + D\, y_{i,t} - \sigma\, j_{i,t}$$

where $I_{i,t}$ is investment, $C_{i,t-1}$ is the firm's capital stock and δ is the rate of depreciation. In the empirical specifications, the user cost of capital are modelled as a function of time dummy variables and firm-specific effects. Following Bond et al. (1994), I use a generalized dynamic version which nests equation (2) in the empirical equation

(3) $$\frac{I_{i,t}}{C_{i,t-1}} = \rho^I \frac{I_{i,t-1}}{C_{i,t-2}} + \beta_1^I D y_{i,t} + \beta_2^I D y_{i,t-1} + d_t^I + \eta_i^I + \varepsilon_{i,t}^I$$

where $e_{i,t}^I$ is an error term, d_t^I represents time dummies, and h_i^I captures unobserved heterogeneity at the firm level. The inclusion of cash flow effects then renders the basic empirical specification

(4a) $$\frac{I_{i,t}}{C_{i,t-1}} = \rho^I \frac{I_{i,t-1}}{C_{i,t-2}} + \beta_1^I D y_{i,t} + \beta_2^I D y_{i,t-1} + \beta_3^I \frac{CF_{i,t}}{C_{i,t-1}} + \beta_4^I \frac{CF_{i,t-1}}{C_{i,t-2}} + d_t^I + \eta_i^I + \varepsilon_{i,t}^I\,.$$

The corresponding R&D equation can be derived in the same way by treating R&D and investment completely symetrically. Thus,

(4b)

$$\frac{R_{i,t}}{K_{i,t-1}} = \rho^R \frac{R_{i,t-1}}{K_{i,t-2}} + \beta_1^R \Delta y_{i,t} + \beta_2^R \Delta y_{i,t-1} + \beta_3^R \frac{CF_{i,t}}{K_{i,t-1}} + \beta_4^R \frac{CF_{i,t-1}}{K_{i,t-2}} + d_t^R + \eta_i^R + \varepsilon_{i,t}^R .$$

Here, $R_{i,t}$ denotes the firm's R&D expenditures and $K_{i,t}$ is the respective "knowledge" capital stock. The computation of this variable and potential complications are described in the data appendix.

These equations can be estimated in first differences in order to eliminate the firm-specific effects. Arellano and Bond (1991) describe a family of GMM estimators which can be employed for this purpose and have a number of desirable properties. Since we want to allow for endogenous relationships between the right-hand side variables and the error terms, suitable instruments have to be devised to estimate the equation. Arellano and Bond suggest using lagged values of the right-hand side variables and of the autoregressive term. If the original error term $\varepsilon_{i,t}$ follows a white noise process, then values (in levels) of these variables lagged two or more periods will be admissible instruments. If the error term has a moving average structure, longer lags will have to be considered. Arellano and Bond describe a number of test statistics that can be used to test for violations of various assumptions, in particular for serial autocorrelation and validity of the instruments.[9]

4.2 Error-Correction Models

Bond et al. (1994) follow Bean (1981) and nest equation (1) directly in an error-correction framework of the type

(5a)

$$\frac{I_{i,t}}{C_{i,t-1}} = \rho^I \frac{I_{i,t-1}}{C_{i,t-2}} + \beta_1^I D y_{i,t} + \beta_2^I D y_{i,t-1} + \phi^I \left(c_{i,t-2} - y_{i,t-2} \right)$$
$$+ \beta_3^I \frac{CF_{i,t}}{C_{i,t-1}} + \beta_4^I \frac{CF_{i,t-1}}{C_{i,t-2}} + d_t^I + \eta_i^I + \varepsilon_{i,t}^I$$

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9 For details on the estimation technique, see Arellano and Bond (1991).

$$\text{(5b)} \qquad \begin{aligned} \frac{R_{i,t}}{K_{i,t-1}} &= \rho^R \frac{R_{i,t-1}}{K_{i,t-2}} + \beta_1^R Dy_{i,t} + \beta_2^R Dy_{i,t-1} + \phi^R \left(k_{i,t-2} - y_{i,t-2}\right) \\ &+ \beta_3^R \frac{CF_{i,t}}{K_{i,t-1}} + \beta_4^R \frac{CF_{i,t-1}}{K_{i,t-2}} + d_t^R + \eta_i^R + \varepsilon_{i,t}^R \end{aligned} .$$

which has equation (1) as its long-run solution. Negative estimates for the coefficients ϕ^R and ϕ^I would indicate error-correcting behavior for the respective type of investment. Since (5a) and (5b) also nest the respective accelerator models, this specifation is particularly convenient. Deviations from constant returns can be tested by including the logarithm of output as an additional regressor in (5a) and (5b). Deviations of the respective coefficient from zero would indicate a violation of the constant-returns assumption (see Bean 1981).

4.3 Euler Equations

Due to the aforementioned ambiguities regarding the interpretation of the cash flow effects in reduced-form equations, possibly significant cash flow coefficients in the accelerator and error-correction specifications are not fully convincing. In particular, they cannot unambiguously be interpreted as evidence for financing constraints, since cash flow may be correlated with investment demand.

It is therefore desirable to employ a structural framework in order to confirm or reject findings from the accelerator and error correction equation models. Such models have been used successfully by Bond and Meghir (1994) and Whited (1992), among others. Including R&D activity in a *structural* estimation approach requires that the theoretical framework encompass at least[10] two distinct types of capital (knowledge capital and tangible capital). Studies of this type are still rare in the literature[11], but such a model - based on the work of Bond and Meghir (1994) - is derived and described in the appendix where I show that - under suitable assumptions - the empirical Euler equation for investment in tangible capital can be written as

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10 It is not clear that labor can be treated as adjustable without causing adjustment costs to the firm. This problem applies obviously to industries with high human capital, but it could be particularly pronounced in the Federal Republic which heavily restricts employer's ability to layoff workers. The Euler equation model in the appendix is in principle amenable to an extension which would allow for costs in adjusting the labor force, but such an extension is beyond the scope of this paper.

11 See the survey by Chirinko (1993a). Chirinko (1993b) estimates a model with multiple capital stocks on the basis of the *q* approach.

(6a)
$$\left(\frac{I}{C}\right)_{t+1} = \beta_1^I\left(\frac{I}{C}\right)_t + \beta_2^I\left(\frac{I}{C}\right)_t^2 + \beta_3^I\left(\frac{X}{C}\right)_t + \beta_4^I\left(\frac{Y}{C}\right)_t + \beta_5^I\left(\frac{R}{C}\right)_t + \beta_6^I\left(\frac{R}{C}\right)_t^2 + \alpha_t^I + \alpha_i^I + \psi_t^I .$$

Analogously, one can derive the empirical equation for the firm's R&D spending

(6b)
$$\left(\frac{R}{K}\right)_{t+1} = \beta_1^R\left(\frac{R}{K}\right)_t + \beta_2^R\left(\frac{R}{K}\right)_t^2 + \beta_3^R\left(\frac{X}{K}\right)_t + \beta_4^R\left(\frac{Y}{K}\right)_t + \beta_5^R\left(\frac{I}{K}\right)_t + \beta_6^R\left(\frac{I}{K}\right)_t^2 + \alpha_t^R + \alpha_i^R + \psi_t^R$$

In these equations, K is the knowledge capital stock, and C is the stock of physical capital, I is investment in physical capital and R the firm's R&D expenditures. Y denotes the firm's output (measured as sales) and X is the firm's gross profit.[12] For both equations, the theoretical model yields the parameter restrictions $\beta_1 > 1$, $\beta_2 < -1$, $\beta_3 < 0$, $\beta_4 > 0$, $\beta_5 > 0$, and $\beta_6 < 0$. Details are provided in the appendix. These coefficients are themselves functions of underlying structural parameters. However, as in most other papers using Euler equations of this type, the resulting restrictions across coefficients will not be tested or enforced in this paper.

The Euler equations derived in the appendix specify investment and R&D equations under the null hypothesis of no financing constraints. There is no explicit structural model of the firm's investment behavior under the alternative. The logic of testing the model is the following. Presumably, if financing constraints exist for at least a subsample of firms, then the parameter restrictions just described will not be satisfied. Moreover, in that case other specification tests, e.g. the Sargan test and tests for serial correlation may also yield significant test statistics.[13] If the subsample of firms affected by financing constraints can be identified, then separate estimates for the respective groups of firms should lead to a rejection in one case, and acceptance of the Euler equations in the other. In practice, it may be difficult to achieve a full acceptance of the model, since any deviation from the assumptions underlying the structural model may lead to deviations from the expected coefficient patterns. Thus, obtaining the right signs on the parameters and moving closer to the expected coefficient size after the sample-split has been implemented can be seen as an imperfect, but still positive result.

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12 See the data appendix and the derivation of the Euler equations for details on the variable definition.

13 For details on the logic of testing these models see Zeldes (1989) and Bond and Meghir (1994).

5 Estimation Results

5.1 Accelerator and Error-Correction Models

In Table 3, I report estimates based on the accelerator specifications in equations (4a) and (4b). In the overall sample, there are significant cash flow effects in investment, but not in R&D spending. Splitting the sample according to size reveals a more complex pattern. Apparently, the significant effects in the investment equation are driven by the subsample of smaller firms where cash flow effects remain highly significant while there is no statistically significant effect for the subsample of larger firms. A similar result is obtained for the R&D equations, but the associated cash flow coefficients are considerably smaller. The test statistics for these results do not suggest any problems with the choice of instruments and/or their time structure. The Sargan test statistic is never significant at the 5 percent level, nor are the tests for second order serial correlation. However, one should note that the output accelerator effects are not particularly convincing if the underlying model is taken at face value. These coefficients are either quite small and typically insignificant, or they carry the wrong sign. This may indicate a problem with the choice of the output variables (sales) which does not account for changes in inventories or with the industry-specific sales deflators used in this study.[14]

The implications of allowing for error-correcting behavior are analyzed in Table 4. Note that this equation nests the previous specification. The error correction terms have the expected negative signs, and they are significant in all equations, except for the investment equations for the overall sample and the group of smaller firms. The test statistics do not point to any misspecification, once the equations are estimated separately for the two subsamples. However, it is disturbing that the coefficient of $log\ (Y_{t-2})$ is also significantly negative in most of the columns of Table 4. This would suggest strong decreasing returns to scale which appears implausible. Again, this effect might be triggered by problems with the output variable used in this study or by the fact that the time series is too short. One can enforce the constant returns to scale assumption in these data by simply omitting the variable $log(Y_{t-2})$, but this does not change the coefficients of the remaining variables strongly, although cash flow effects become slightly stronger in the restricted specification. For larger firms, the accelerator terms assume reasonable values in Table 4.

For the ECM specification, there is little evidence of any cash flow effects for investment or R&D in the overall sample. The test statistic for the joint test of the cash flow terms in the investment and R&D equations is insignificant. The admission of error-correcting behavior appears to lead to lower cash flow effects in all of the specifications. For

[14] For firms that sell products from accumulated stocks, output is biased upwards, and vice versa for firms accumulating stocks of finished and semi-finished products.

smaller *and* larger firms, cash flow does not appear to have a significant effect on investment. However, in the R&D equation, there are significant cash flow effects for both subsamples. The cash flow coefficients are considerably larger for the smaller companies, but their overall size 0.079 (=0.050+0.029) is still quite small.

Experimenting with different sample splits provided evidence of a size-contingent cash flow effect in the subsample of smaller firms. In Table 4, the significance level of the test statistic for the joint effect of cash flow variables in the investment equation for smaller firms is p=0.077. Reestimating the error-correction model for investment with a sample split into three groups (see Table 5) yields significant cash flow effects at the confidence level of p=0.005 for the group consisting of the 71 smallest firms in the sample while no significant effects emerge for the two other groups. Moreover, it is interesting that error-correcting behavior appears to be relevant for the investment decisions of larger firms, but not for the very smallest firms in this sample. This result would support the presumption that smaller firms employ rather flexible investment processes. As to the R&D equations, splitting the sample into three groups did not provide qualitatively new results. Small but significant cash flow effects persist, and they tend to be slightly larger for the smaller firms.

These results suggest that the data may not be suitable to test for financing constraints: if they are present and indeed apparent in the form of cash flow effects, they are likely to affect only the very smallest firms in this sample. This does not mean that these firms are of little relevance: small and medium-sized firms with fewer than 500 employees constitute the lion's share of Germany's firm population and account for about 70 percent of employment, and a reliable assessment of their financing situation would be quite important. But these firms tend to be systematically underrepresented in financial accounts data of the form used here.

Summarizing the results from the accelerator and error correction specifications used here, there is some evidence pointing to size-contingent cash flow effects, both for R&D and investment. These effects persist even after accounting for relatively complex adjustment dynamics, although the effects are clearly reduced in size once such adjustment mechanisms are allowed for. This result has been described before by Bond et al. (1997). Even without attempting to interpret the cash flow effects in one way or another, one lesson from these results is certainly that simple linear specifications (such as the accelerator model) will tend to deliver inflated cash flow effects, and that the results from studies not introducing more complex (and presumably realistic) adjustment processes ought to be viewed with caution.

5.2 Euler Equation Results

Results from Euler equation estimates for investment in tangible capital are presented in the left-hand panel of Table 6. The GMM technique used in the previous sections is again chosen to estimate the equations. In each case I start with the assumption that values of the right-hand side variables lagged two or more years are admissible instruments. Both the admissibility of instruments and the serial correlation structure are tested. If serial correlation of second order is detected, the error term in (6a) or (6b) may be MA(1), and valid instruments have to be lagged at least three periods. The choice of instruments is indicated in the last line of each column in Table 6.

For the overall sample, the coefficient estimates are nowhere close to their expected size, and in many cases the signs do not correspond to the theoretical predictions. This should be expected if financing constraints are present. But it is more likely that it indicates general data problems, or simply some mismatch between the assumptions of the theoretical model and real-world investment behavior. Introducing the distinction between small and large firms goes some way to produce clearer patterns and to support the notion that the Euler equation is more likely to fail for smaller firms. For larger firms, the coefficient sizes of the first two terms are still far from the unit value.[15] The cash flow term assumes the predicted negative sign for the larger firms while it is positive in the other subsample, but the coefficients are insignificant in both cases. While the estimates are quite imprecise overall, it is nonetheless clear that the subsample of larger firms corresponds much better to the expected patterns. In terms of sign restrictions derived from theory, only the last two R&D terms carry the wrong sign, but they are jointly insignificant (p=0.302). Nesting both estimates by using a full set of size interaction terms and testing the significance of the interacted terms indicates that the coefficient vectors for the two subsamples differ in statistical terms (p=0.03). Since the test statistics indicate second-order serial correlation in the subsample of smaller firms, I also estimated the Euler equation with instruments lagged at least 3 periods. However, there was no improvement in the test statistic, suggesting that other sources of misspecification may be present as well. Recall that the larger firms did not show any sign of financing constraints for investment in Table 4 and 5, while the smaller firms appeared to be affected by such effects. Thus, while the investment estimates in Table 6 are still far from being satisfactory, they are not grossly inconsistent with the previous results.

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[15] Some experiments with different estimators (e.g. the Blundell-Bond (1995) GMM system estimator) suggest that the results improve considerably once other estimation techniques are employed. But even in this case, the coefficients for the subsample of smaller firms are significantly below the unit value suggested by theory.

The results from the R&D Euler equations are not informative. Again, the specification for the overall sample does not perform well, and in this case there is no sign of major improvement once the equation is estimated for the subsamples. Changing the instrument set (e.g. in the third column of the right-hand side panel in Table 6) in order to avoid problems from second-order correlation of the error terms also did not lead to any improvement.

Taken together, the results of the Euler tests are disappointing. Clearly, the sample is still relatively small, and the estimation approach required consumes a large number of degrees of freedom. Differencing and the use of lagged values as instruments subtracts at least two observations from each time series. On the positive side, the sample split according to firm size appears to move the coefficient estimates for capital investment by larger firms in the right direction. But they are still far from the expected value under the null hypothesis of no financing constraints. Note that this result is consistent with the previous estimates - the weakest evidence of cash flow effects on investment was found for large firms.

Assuming that the rejection of the Euler equations for smaller firms is driven by financing constraints, there are a number of explanations why they also fail for larger firms. That subsample may still contain some firms which experience genuine financing constraints. Detection and identification of these firms may require the use of additional variables on capital structure and other firm characteristics. Note also that the failure of the Euler equations is particularly clear for the R&D equation. This may point to problems in either the theoretical formulation of the R&D law of motion (see the appendix) or in the measurement of the capital stock. Longer time series would definitely be helpful towards mitigating existing data problems and exploring alternative specifications.

5.3 Additional Evidence from Survey Data

Given that the cash flow effects emerging from Table 4 and 5 are not unambiguous and that the Euler equation framework does not deliver completely reliable results either, it may be helpful to look for additional evidence on the role of firm size for the relationship between finance and investment. Such indirect evidence is available from an innovation survey conducted in 1995 in Germany. In this postal survey, respondents (mostly R&D managers) were asked whether a lack of equity or of debt finance was a serious impediment to their innovation projects. The answers ranged from "not at all" to "very much" with five ordinal response categories. For 51 firms in the sample used in this study, data from the 1995 survey could be matched. 29 percent of the small firms (according to the definition used in Table 5) in this sample responded that there were debt constraints (i.e. marked either of the two highest response categories), but only 5 percent of the larger firms did so. The difference is significant at the level of p=0.022.

Similarly, 36 percent of the smallest firms indicated that lack of equity capital was an impediment for innovation activities, while again only 5 percent of the larger firms did so (p=0.005). I also employed ordered logit models with a dummy variable for the group of the smallest firms (as in Table 5) as the independent variable. It turns out that the coefficient for this dummy variable is significant at the level of p=0.011 for the equity question and at the level of p=0.023 for the debt question. Thus, these subjective responses appear to support the result that small firms have a higher propensity of being financially constrained.

Much can be said against the cash flow effects presented above in Table 4 and Table 5, and serious objections may be raised against using subjective survey responses.[16] Nonetheless, the evidence from both sources is consistent and provides tentative support that the cash flow effects detected in the panel data are indeed an outcome of financing constraints at the firm level. However, important limitations remain and call for more direct evidence than can be provided via this relatively small sample of firms for which we observe survey data.

6 Conclusions and Extensions

The present analysis has been limited in many ways, mostly due to data constraints that will hopefully be relaxed over time. The sample used here is not representative, and thus the results need to be taken with a grain of salt. While all of these caveats call for a cautious interpretation of the results, the existing evidence suggests that firm size has a potentially strong impact on the relationship between cash flow and investment in physical and knowledge capital. For the group of smaller firms, there appears to be some sensitivity of R&D and of investment to the firm’s cash flow. While this result can be rationalized by pointing to the basic ambiguity in interpreting cash flow effects, it is much harder to explain the differences between results for smaller and larger firms on this basis. Explaining this result away would amount to assuming that cash flow has no (or a negligible) investment demand component for larger firms, but indeed some informational content about investment opportunities for the group of smaller firms. This notion appears somewhat odd. Moreover, the survey evidence summarized in section 5.3 provides suggestive evidence that smaller firms may indeed be facing financing constraints in Germany. For larger firms, the evidence is broadly consistent with the results reported by Bond et al. (1997) for a sample of German stock market firms. One

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[16] The evidence concerning the subjective responses is of course ambiguous because even in the absence of any informational asymmetries, one would expect that the group of small firms includes a relatively large number of "lemons". Whether the identity of these is known to external financiers or not, enterprises in this group of small firms will - on average - face greater financing problems than larger firms would.

should also note that the Jensen hypothesis of free cash flow would not lend itself easily to an explanation of these results, either, unless one assumes that free cash flow is a particularly astute problem for relatively small firms. Since these firms are presumably less likely to suffer from intransparencies of managerial behavior than larger ones, an explanation based on differences in the extent of free cash does not seem particularly plausible.

However, to distinguish between the competing hypotheses more clearly, it is necessary to implement structural models of investment and R&D behavior. This paper attempted to do so by deriving specifications for investment and R&D Euler equations. With the exception of the subsample of large firms in the case of capital investment, the parameter restrictions implied by this model do not appear to be consistent with the data. While such a rejection could be caused by financing constraints, it is probably more realistic to argue that the sample is too small for a precise estimation of the Euler equation coefficients, or that the model itself is too restrictive to describe the complexity of investment processes in a satisfactory way. Since it is desirable to include German firms not traded in the stock market, it seems fruitful to explore as an alternative the applicability of the structural approach pioneered by Abel and Blanchard (1986). In this approach a separate equation for estimating the shadow value of capital needs to be implemented, and the predicted values are then used as a substitute of Tobin's *q*.

Finally, international comparisons as in Bond et al. (1997) may constitute a productive approach to the question posed in this paper. It should be particularly instructive to study differences between firms in countries with market-based financing systems (e.g. the U.S. and the United Kingdom) and systems which relie strongly on links between banks and firms (e.g. in continental Europe). In such a comparison, the investment demand component of the cash flow variable can presumably be controlled for by choosing appropriate groups of firms for between-country comparisons.

If these avenues are pursued further, a stronger case *for or against* the existence of financing constraints in German firms can presumably be made. At this point, there is some weak evidence that such constraints may exist for investment in capital goods in relatively small firms, but the empirical results are still far less than satisfactory.

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8 Data Appendix

In 1985, several changes were introduced into German corporate law (§289 Handelsgesetzbuch) , most of them triggered by the European Community's Fourth Company Law directive on harmonization of national requirements pertaining to financial statements. Thus starting in the fiscal year of 1987, all limited liability corporations (Gesellschaften mit beschränkter Haftung - GmbHs) and stock-based corporations (Aktiengesellschaften - AGs) had to submit their annual financial statements to the Commercial Register. Only the larger firms have to have their statements audited, smaller ones need not submit a statement of profits and losses, and the balance sheet can be abbreviated significantly. Medium-sized and large GmbHs are required to publish their statements in the Bundesanzeiger. The size requirements are satisfied if two or more of the following conditions are met: revenues in excess of DM 32 million, more than 250 employees, or balance-sheet total in excess of DM 15 million.

A discussion of the situation of the business (Lagebericht) is part of the published statement. Besides establishing new publication requirements, the 1985 law also requires firms to comment on their R&D acitivities (§289 Handelsgesetzbuch, para 2). However, there is no legal specification as to the format of R&D reporting.

The data used in this paper originate with financial statements and respective appendices published in the Bundesanzeiger. To obtain the respective data, the 1993 volume of the Bundesanzeiger was searched for any published statements that indicated R&D activities. These roughly 900 records provided the „master list" of companies for the data collection. The statements of these companies were then tracked backwards to 1987 and forward to 1994. Whenever companies provided quantitative items on their R&D activities, the record was entered into the database. A list of companies which had published similar information in 1987 was provided by B. Schwitalla and H. Grupp and used to check the completeness of our own data search. See Schwitalla (1993) for a description of the 1987 cross-section.

Quantitative data on R&D activity were recorded from the Bundesanzeiger if one or several of the following items were available: i) R&D expenditures, ii) R&D employees, iii) R&D intensity with respect to sales, iv) R&D intensity with respect to total number of employees, v) growth rates of any of these indicators. For about 200 firms, comparable data from the Mannheim Innovation Panel (MIP) were available for two or more years. A comparison of the R&D figures from the two sources yielded the result that the Bundesanzeiger figures were less frequently rounded off than the survey data. Moreover, whenever the business responding to the survey could be matched in terms of employees and revenues (about 150 cases), the R&D figures were nearly identical, leaving aside rounding errors in the survey responses. Since the MIP survey explicitly asks for R&D according to the Frascati definitions, the correspondence between the two sources is reassuring.

Since the operationalization of the theoretical model requires data on R&D expenditures, the respective information had to be imputed for a small number of cases (105 out of 2300) for which it was not available directly. In the case of items ii) and iv), industry-specific regression coefficients from a previous analysis of the 1987 and 1989 Stifterverband surveys were used to impute R&D expenditures from R&D personnel data. These regression results are available upon request. As one should expect, the number of R&D employees and R&D expenditures are highly correlated (r=0.98), and inclusion of time and industry dummies in these regressions generates a good fit.

The data obtained from the Bundesanzeiger were matched to commercially available balance sheet data published by Creditreform, a large credit rating agency. While the Bundesanzeiger entries contain in principle all of the necessary data, it was not feasible to enter the full balance sheet information for these companies. Thus the availability of the matching information in the Creditreform database is currently still a constraint for about 300 observations.

<u>Investment (I).</u> The data on additions to plant, property and equipment came from the detailed Anlagenspiegel tabulation of assets in each of the Bundesanzeiger entries. The tabulation also includes their value at historical cost.

<u>Output (Y).</u> Computing time series for output (sales) followed the suggestions in the data appendix of Bond et al. (1994). The deflators used for computing real output were at the two-digit SYPRO level.

<u>Cash Flow (CF).</u>For the purpose of the regressions in sections 4.1 and 4.2, cash flow is computed as funds available for investment and R&D spending, i.e. as net income plus depreciation plus R&D expenditures. The latter correction is necessary, since R&D is expensed in Germany (as in the U.S., see Himmelberg and Petersen 1994, Hall 1992). Obviously, this does not hold for the investment portion (buildings, plant and equipment) of R&D laboratories, but the respective share of these expenditures is below 10 percent. Note that a correction of the cash flow variable would also necessitate reducing the physical investment figures by the corresponding amount. I experimented with such a correction of the investment and cash flow variables for the investment share of the R&D budget, but the results presented in this paper do not change in any major way. For that reason, the simpler procedure is followed here.

<u>Gross Profit (X).</u> For the estimation of the Euler equations described in section 4.3, the theoretical derivation of the model implies that the most appropriate measure is given as gross operating profits. For the data used here, the measure was computed as cash flow (see above) plus interest plus tax payments.

The capital stock (C) measure was computed by adjusting the historic cost values taken from the Anlagenspiegel for inflation, and by applying a perpetual inventory procedure with a depreciation of 8 percent per annum for all years following the first year for which historic cost data were available. The choice of this depreciation rate reflects average economic depreciation across German industries.

The knowledge capital stocks (K) in 1987, the initial year of most of the time series observations, were again computed from a permanent growth approximation as in Harhoff (1997), assuming a pre-sample growth rate of 6 percent for all firms. Stock data for the following years were computed on the basis of perpetual inventory calculations, using a depreciation rate of 15 percent. Note that the data do not allow for a correction of the double-counting problem - a small portion of R&D expenditures (on average about 10 percent in Germany) is capital investment and thus included in the stock of phyisical capital. See Schankerman (1981) for a discussion of potential distortions arising from this problem.

Exclusion procedures. From the data thus constructed, any overlapping entries were deleted. Priority was given to consolidated financial statements whenever possible, though the database still contains a large number of nonconsolidated statements, in particular when comparability over time requires their use. Non-profit firms and subsidiaries of foreign firms were deleted as well. For the purpose of this study, only manufacturing firms were included.

Cleaning procedures and sample trimming. Observations were excluded if the following variables were below the lower centile or beyond the upper centile of the respective distribution: I/C, CF/C and the output growth rate.

Final Analysis at the Firm Level. The fact that some subsidiaries report their R&D expenditures in the Bundesanzeiger can be troublesome for any kind of analyis of R&D or financial performance. In this particular case, the relationship between cash flow and R&D might be affected by strategic issues or attempts to minimize overall taxes by strategic choice of transaction prices, etc. Moreover, the delination of R&D-performing units may be affected. In order to exclude cases in which problems were likely to occur, all firms that had passed the above selection and cleaning procedures were analyzed individually. Data on ownership structure from Creditreform was used to detect subsidiaries. Data from the Mannheim Innovation Panel was consulted to rule out cases in which R&D for a subsidiary was conducted by other business units or centralized R&D facilities. Cases that were deemed to problematic to deal with or sufficiently suspect were discarded. By applying this final cleaning procedure, the sample shrank again from about 1640 observations to 1365 observations.

Figure 1
R&D Intensity Distribution (1990)

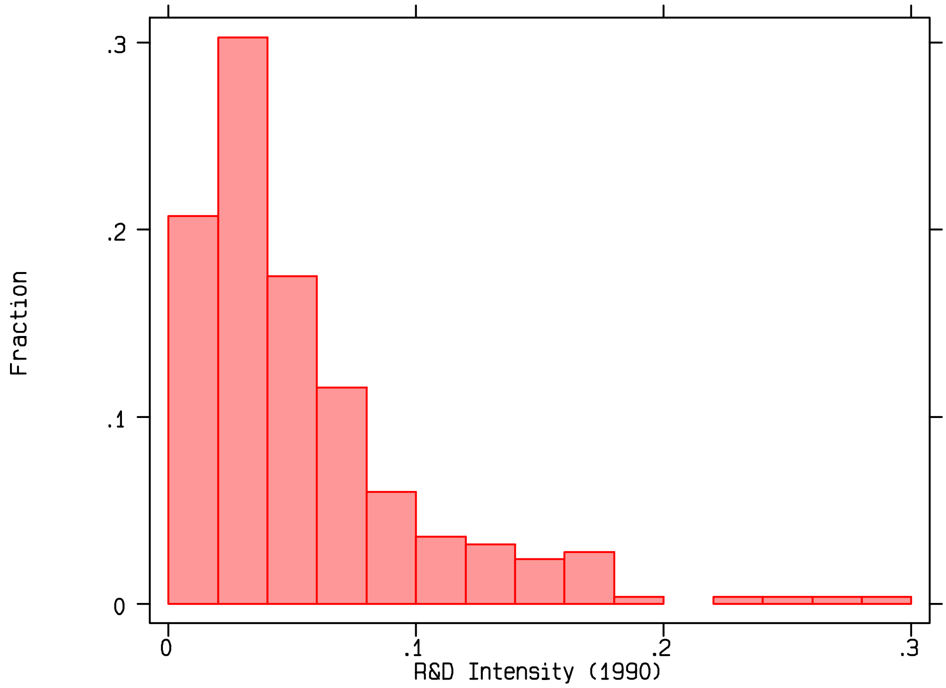

Table 1

Sectoral Composition of the Sample

SYPRO	Sector	Number of Firms
24,40	Chemicals, Pharmaceuticals	46
58, 59	Plastic and Rubber Products	12
25, 51, 52	Mining, Quarrying, Ceramic Products	12
21, 22	Petroleum Refineries	7
27, 28, 29	Metal and Metal Products	11
30, 31	Structural Steel Products	7
32, 50	Machinery	66
33, 34, 35	Road Vehicles	15
36, 37	Electrical Products, Precision and Optical Goods	49
38, 39	Ironware, Sheet Metal	5
53-57, 61-64	Wood Products, Pulp, Paper and Paperboard, Printing and Duplication, Leather, Leatherware, Footware, Textiles and Apparel	3
68, 69	Food, Beverages and Tobacco	3
Total		236

Table 2

Descriptive Statistics

(215 Firms - 1990)

Variable	Mean	S.E.	Lower Quartile	Median	Upper Quartile
I/C	0.139	0.105	0.075	0.108	0.174
CF/C	0.302	0.256	0.160	0.232	0.341
Y/C	2.637	2.083	1.400	1.949	2.965
R/C	0.136	0.139	0.050	0.093	0.179
R/K	0.199	0.093	0.173	0.201	0.221
I/R	1.824	2.439	0.618	1.156	2.024
Y	3660.4	10620.0	157.8	445.7	1695.2
I	229.1	698.6	7.8	28.0	91.5
R	163.6	577.0	7.2	18.8	72.5
C	2246.1	7110.4	74.5	196.9	870.1
K	831.8	3013.2	36.8	94.2	327.4
Employees	15006	43862	791	2291	6909
Net Book Value (PPE)	1000.9	3222.5	32.6	94.9	477.1

Note: Absolute values for *Y*, *I*, *R*, *C*, *K* and net book value (PPE) in 1985 million DM. All capital ratios for physical capital were computed using the capital stock measure computed from historical cost data.

Table 3

Accelerator Models

Dependent Variable	I_t/C_{t-1}			Dependent Variable	R_t/K_{t-1}		
	Full Sample	Smaller Firms	Larger Firms		Full Sample	Smaller Firms	Larger Firms
I_{t-1}/C_{t-2}	-0.051 (0.055)	-0.087 (0.051)	0.429 (0.178)	R_{t-1}/K_{t-2}	0.152 (0.114)	0.054 (0.132)	0.258 (0.137)
CF_t/C_{t-1}	0.178 (0.192)	0.126 (0.199)	0.072 (0.104)	CF_t/K_{t-1}	0.022 (0.021)	0.065 (0.024)	0.025 (0.015)
CF_{t-1}/C_{t-2}	0.314 (0.063)	0.322 (0.065)	0.080 (0.138)	CF_{t-1}/K_{t-2}	0.027 (0.020)	0.032 (0.036)	0.014 (0.010)
Δy_t	-0.016 (0.082)	-0.021 (0.096)	-0.012 (0.056)	Δy_t	0.020 (0.035)	-0.007 (0.033)	0.029 (0.030)
Δy_{t-1}	-0.002 (0.073)	-0.006 (0.093)	0.012 (0.012)	Δy_{t-1}	0.007 (0.016)	0.008 (0.019)	-0.008 (0.017)
Test Statistics				Test Statistics			
Sargan Test	39.0 (37) p=0.381	41.3 (37) p=0.287	43.2 (37) p=0.224	Sargan Test	44.9 (37) p=0.176	39.5 (37) p=0.361	35.5 (37) p=0.540
1st Order Serial Corr.	-2.219	-2.363	-1.832	1st Order Serial Corr.	-2.053	-1.458	-2.809
2nd Order Serial Corr.	-1.753	-1.616	0.410	2nd Order Serial Corr.	1.246	0.649	0.875
Wald Test on Cash Flow Terms	p<0.001	p<0.001	p=0.785	Wald Test on Cash Flow Terms	p=0.161	p=0.017	p=0.057
Observations	673	306	367	Observations	673	306	367
Firms	(213)	(106)	(107)	Firms	(213)	(106)	(107)
Instruments	t-2,...t-5	t-2,...t-5	t-2,...t-5	Instruments	t-2,...t-5	t-2,...t-5	t-2,...t-5

Note: Estimation in first differences using the DPD software (Arellano and Bond 1988). All regression include time dummy variables for the respective years of observation. The sample was split at the median of initial year sales.

Table 4
Error Correction Models

Dependent Variable	I_t/C_{t-1}			Dependent Variable	R_t/K_{t-1}		
	Full Sample	Smaller Firms	Larger Firms		Full Sample	Smaller Firms	Larger Firms
I_{t-1}/C_{t-2}	-0.204	-0.223	-0.129	R_{t-1}/K_{t-2}	-0.234	-0.244	-0.191
	(0.114)	(0.124)	(0.153)		(0.104)	(0.154)	(0.157)
CF_t/C_{t-1}	0.010	-0.001	-0.088	CF_t/K_{t-1}	0.003	0.050	0.023
	(0.263)	(0.263)	(0.134)		(0.027)	(0.019)	(0.015)
CF_{t-1}/C_{t-2}	0.141	0.214	-0.117	CF_{t-1}/K_{t-2}	0.025	0.029	0.018
	(0.113)	(0.136)	(0.129)		(0.018)	(0.024)	(0.010)
Δy_t	-0.069	-0.038	0.113	Δy_t	0.078	0.026	0.080
	(0.114)	(0.090)	(0.054)		(0.057)	(0.054)	(0.034)
Δy_{t-1}	-0.003	-0.024	0.231	Δy_{t-1}	0.136	0.044	0.124
	(0.132)	(0.124)	(0.097)		(0.080)	(0.079)	(0.060)
$c_{t-2} - y_{t-2}$	-0.252	-0.240	-0.417	$k_{t-2} - y_{t-2}$	-0.248	-0.229	-0.236
	(0.158)	(0.207)	(0.090)		(0.070)	(0.067)	(0.042)
y_{t-2}	-0.224	-0.257	-0.147	y_{t-2}	-0.096	-0.175	-0.076
	(0.196)	(0.182)	(0.062)		(0.055)	(0.087)	(0.025)
<u>Test Statistics</u>				<u>Test Statistics</u>			
Sargan Test	37.2 (37)	39.4 (37)	40.0 (37)	Sargan Test	30.7 (37)	38.2 (37)	30.9 (37)
	p=0.462	p=0.364	p=0.340		p=0.756	p=0.414	p=0.751
1st Order Serial Corr.	-1.935	-2.181	-1.717	1st Order Serial Corr.	-0.298	-0.237	-0.763
2nd Order Serial Corr.	-1.756	-1.385	0.061	2nd Order Serial Corr.	0.928	0.933	0.343
Wald Test on Cash Flow Terms	p=0.228	p=0.077	p=0.640	Wald Test on Cash Flow Terms	p=0.341	p=0.031	p=0.041
Observations	673	306	367	Observations	673	306	367
Firms	(213)	(106)	(107)	Firms	(213)	(106)	(107)
Instruments	t-2 ... t-5	t-2 ... t-5	t-2 ... t-5		t-2,...t-5	t-2,...t-5	t-2,...t-5

Note: Estimation in first differences using the DPD software (Arellano and Bond 1988). All regression include time dummy variables for the respective years of observation. The sample was split at the median of initial year sales.

Table 5
Alternative Sample Split for Investment Error Correction Model

	Dependent Variable	I_t/C_{t-1}	
	Initial Year Sales < 208 Mill. DM	208 Mill. DM <= Initial Year Sales < 950 Mill. DM	Initial Year Sales >= 950 Mill. DM
I_{t-1}/C_{t-2}	-0.078	-0.412	-0.106
	(0.160)	(0.122)	(0.160)
CF_t/C_{t-1}	0.221	0.048	-0.031
	(0.377)	(0.091)	(0.067)
CF_{t-1}/C_{t-2}	0.252	0.157	-0.069
	(0.087)	(0.080)	(0.101)
Δy_t	0.014	0.110	0.135
	(0.186)	(0.061)	(0.056)
Δy_{t-1}	-0.149	0.147	0.182
	(0.201)	(0.087)	(0.073)
$c_{t-2} - y_{t-2}$	-0.073	-0.351	-0.339
	(0.226)	(0.102)	(0.069)
y_{t-2}	-0.245	-0.211	-0.125
	(0.249)	(0.115)	(0.059)
Test Statistics			
Sargan Test	36.8 (37) p=0.481	33.0 (37) p=0.656	37.0 (37) p=0.117
1st Order Serial Corr.	-1.966	-1.214	-2.035
2nd Order Serial Corr.	-1.354	-2.195	-1.088
Wald Test on all Cash Flow Terms	p=0.005	p=0.142	p=0.780
Observations	206	205	262
Firms	(71)	(71)	(71)
Instruments	t-2 ... t-5	t-2 ... t-5	t-2 ... t-5

Note: Estimation in first differences using the DPD software (Arellano and Bond 1988). All regression include time dummy variables for the respective years of observation.

Table 6

Euler Equation Results

Investment Equation	Full Sample	Smaller Firms	Smaller Firms	Larger Firms
$(I/C)_t$	0.364 (0.148)	0.191 (0.170)	0.081 (0.325)	0.674 (0.153)
$(I/C)_t^2$	-0.280 (0.275)	-0.074 (0.307)	-0.256 (0.744)	-0.791 (0.327)
$(Y/C)_t$	0.022 (0.009)	0.021 (0.013)	0.013 (0.015)	0.022 (0.007)
$(X/C)_t$	-0.010 (0.006)	-0.009 (0.007)	0.0001 (0.0069)	-0.001 (0.014)
$(R/C)_t$	0.340 (0.300)	0.853 (0.453)	0.576 (0.454)	-0.349 (0.393)
$(R/C)_t^2$	-0.093 (0.265)	-0.538 (0.407)	-0.259 (0.290)	0.876 (0.678)
Test Statistics				
Sargan Test	114.0 (102) p=0.196	103.7 (102) p=0.435	72.4 (66) p=0.275	98.2 (102) p=0.589
1st Order Serial Corr.	-5.410	-4.644	-1.796	-4.532
2nd Order Serial Corr.	-2.256	-2.329	-3.018	-0.828
Observations	893	420	298	473
Firms	(236)	(122)	(103)	(114)
Instruments	**t-2,...t-5**	**t-2,...t-5**	**t-3,...t-5**	**t-2,...t-5**

R&D Equation	Full Sample	Smaller Firms	Smaller Firms	Larger Firms
$(R/K)_t$	-0.058 (0.304)	0.171 (0.301)	0.292 (0.348)	-0.064 (0.259)
$(R/K)_t^2$	0.381 (0.706)	-0.113 (0.726)	-0.215 (0.805)	0.612 (0.689)
$(Y/K)_t$	-0.001 (0.001)	0.001 (0.001)	0.001 (0.002)	-0.002 (0.001)
$(X/K)_t$	0.0002 (0.0001)	0.0002 (0.0001)	0.0007 (0.0021)	0.0003 (0.0008)
$(I/K)_t$	0.0005 (0.0088)	-0.0081 (0.0101)	-0.0086 (0.0116)	0.0385 (0.0163)
$(I/K)_t^2$	0.0004 (0.0012)	0.0015 (0.0011)	0.0013 (0.0014)	-0.0071 (0.0033)
Test Statistics				
Sargan Test	128.6 (102) p=0.278	110.7 (102) p=0.717	79.4 (66) p=0.434	98.9 (102) p=0.920
1st Order Serial Corr.	-3.361	-2.858	-2.630	-5.822
2nd Order Serial Corr.	-1.966	-1.902	-0.386	-0.463
Observations	893	420	298	473
Firms	(236)	(122)	(103)	(114)
Instruments	**t-2,...t-5**	**t-2,...t-5**	**t-3,...t-5**	**t-2,...t-5**

Note: Estimation in first differences using the DPD software (Arellano and Bond 1988). All regression include time dummy variables for the respective years of observation. The sample was split at the median of initial year sales for the sample used in Table 3 (see text).

9 Appendix: Derivation of the Euler Equations

This section derives a structural model of investment and R&D spending in the presence of financing constraints. To avoid cluttered notation, I will only write subscripts for years and not use firm subscripts unless clarity requires it. The firm under consideration in this section has four choice variables. It can determine its level of R&D, investment, labor, and borrowing. R&D and investment contribute to the build-up of the respective capital stocks. For simplicity, I will refer to the capital stock (stock of physical capital) and the knowledge stock (stock of R&D capital). The firm faces two constraints. First, dividend payments are non-negative. The respective shadow value of dividends is then equivalent to the shadow value of internal funds. Second, the firm possibly faces an exogenously given borrowing constraint which limits investment spending if internal funds are exhausted. By definition, the firm cannot issue new equity. This restriction simply acknowledges that issuing of new equity is a rare event in German corporations and therefore not too interesting for the model at hand.

The per period profit of the firm is given by

(A.1) $$\Pi_t = p_t F\left(C_t, K_t, L_t\right) - p_t G(I_t, R_t, C_t, K_t) - w_t L_t - p_t^I I_t - p_t^R R_t$$

where p_t is the price of one unit of output, C_t is the stock of physical capital, K_t is the knowledge capital stock, and L_t is labor with unit cost w_t. The firm utilizes a production function $F\left(C_t, K_t, L_t\right)$ with constant returns to scale and faces adjustment costs captured by the cost function $G(I_t, R_t, C_t, K_t)$ where I_t is investment in physical capital and R_t is the firm's R&D expenditures. The effective prices of investment and R&D are given by p_t^I and p_t^R, respectively.

The balance of sources and uses of funds is specified in

(A.2) $$D_t = \Pi_t + B_t - \left(1 + \left(1 - \tau_t\right) i_{t-1}\right) B_{t-1}$$

where D_t are the firm's dividend payments, B_t is the amount borrowed in period t, τ_t is the corporate tax rate, and i_t is the interest on borrowed funds. Capital market arbitrage (neglecting capital gains and new equity issues) requires the cumulated dividend value of the firm V_t to satisfy

(A.3) $$\left(1 + \left(1 - m_{t+1}\right) i_t\right)\left(V_t - \left(1 - m_t\right) D_t\right) = E_t V_{t+1} .$$

where m_t is the personal tax rate on interest and dividend income and i_t is the interest rate. Solving the arbitrage condition backwards, we can write the value of the firm as

(A.4) $$V_t = E_t \left\{ \sum_{j=0}^{\infty} \beta_{t+j}^t \left(\gamma_{t+j} D_{t+j}\right) \right\}$$

where $\gamma_t = (1 - m_t)$ is the tax preference parameter in the absence of capital gains taxation and $\beta_{t+j}^t = \prod_{i=1}^{j} (1 + r_{t+i-1})^{-1}$ is the j-period discount factor with $j \geq 1, \beta_t^t = 1$ and $r_t = (1 - m_{t+1}) i_t$. Note that these expressions are simplified versions of the tax parameters and discount factor in Bond and Meghir (1994).

The transformation laws for physical and knowledge capital follow the perpetual inventory rules

(A.5) $$C_t = (1 - \delta^I) C_{t-1} + I_t$$

(A.6) $$K_t = (1 - \delta^R) K_{t-1} + R_t$$

where δ^R and δ^I are the respective rates of depreciation. Note that knowledge capital and physical capital are treated analogously here, as has been done in most of the R&D literature.[17] In order to prevent the firm from borrowing and paying the borrowed funds out as dividends, we also require that the following transversality condition

(A.7) $$\lim_{T \to \infty} \left(\prod_{j=0}^{T-1} \beta_{t+j}^t \right) B_T = 0, \forall t$$

holds. Given initial conditions at the beginning of period t, the Bellmann equation characterizes the net present value of the firm as

(A.8) $$V_t(C_{t-1}, K_{t-1}) = \max_{I_t, K_t, L_t, B_t} \left\{ D_t + \beta_t^{t+1} E_t V_{t+1}(C_t, K_t) \right\}$$

subject to the laws of transformation (A.5) and (A.6), and the borrowing and dividend constraints

(A.9) $$B_t \leq B_t^*$$

(A.10) $$D_t \geq 0 .$$

As Stokey and Lucas (1989, ch. 9) show, solving the maximization program in (A.8) is a necessary condition for maximizing the value of the firm given in (A.4). They also state the corresponding regularity conditions on functional forms and stochastic shocks.

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17 This specification for the R&D capital stock is not the only feasible way to portray the transformation law for knowledge capital. For example, Hall and Hayashi (1989) and Klette (1996) have suggested to specify the law of motion as $K_t = K_{t-1}^{1-\alpha} R_t^{\beta}, \quad \alpha, \beta \in (0,1)$ where α is the rate of depreciation of the log capital stock. This functional form assumption has been proposed to capture the non-exclusive character of the existing knowledge stock which presumably does not only enter in production of output but also in the production of new knowledge.

Assuming that managers maximize the value of the firm, we obtain the first-order condition for optimal borrowing

(A.11) $$\left(\gamma_t + \lambda_t^D\right) - \beta_{t+1}^t E_t\left\{\left(1 + (1-\tau_{t+1})i_t\right)\left(\gamma_{t+1} + \lambda_{t+1}^D\right)\right\} - \lambda_t^B = 0 \,.$$

Note that the last left-hand side term stems from the assumed borrowing constraint. While the equations will not be estimated under the alternative hypothesis of binding financing constraints, it is nonetheless instructive to study (A.11) in detail. Consider the case in which borrowing constraints are not binding, i.e. $\lambda_t^B = 0$. With perfect capital markets and risk neutrality, the after tax return on equity and the after-tax return on debt will be equal and (A.11) simplifies to $\left(\gamma_t + \lambda_t^D\right) - E_t\left\{\left(\gamma_{t+1} + \lambda_{t+1}^D\right)\right\} = 0$, i.e. the marginal value of dividend payments will be equalized over time. Once borrowing constraints are present, the respective shadow values will no longer be equal. Again assuming perfect capital markets and risk neutrality, we have $\left(\gamma_t + \lambda_t^D\right) - E_t\left\{\left(\gamma_{t+1} + \lambda_t^B + \lambda_{t+1}^D\right)\right\} = 0$ in this case. The multiplier λ_t^B simply reflects the change in the value of the firm if the debt constraint were relaxed by one unit.

The two Euler equations for investment and R&D can be written as

(A.12) $$\frac{\partial V_t}{\partial C_{t-1}} = \left(1-\delta^I\right)\left(\gamma_t + \lambda_t^D\right)\frac{\partial \Pi_t}{\partial C_t} + \left(1-\delta^I\right)\beta_{t+1}^t E_t\left[\frac{\partial V_{t+1}}{\partial C_t}\right]$$

(A.13) $$\frac{\partial V_t}{\partial K_{t-1}} = \left(1-\delta^R\right)\left(\gamma_t + \lambda_t^D\right)\frac{\partial \Pi_t}{\partial K_t} + \left(1-\delta^R\right)\beta_{t+1}^t E_t\left[\frac{\partial V_{t+1}}{\partial K_t}\right].$$

Combining these with the first-order conditions for investment and R&D yields

(A.14) $$-\left(1-d^I\right)b_{t+1}^t E_t\left\{\left(g_{t+1} + l_{t+1}^D\right)\frac{\P P_{t+1}}{\P I_{t+1}}\right\} = -\left(g_t + l_t^D\right)\frac{\P P_t}{\P I_t} - \left(g_t + l_t^D\right)\frac{\P P_t}{\P C_t}$$

(A.15) $$-\left(1-d^R\right)b_{t+1}^t E_t\left\{\left(g_{t+1} + l_{t+1}^D\right)\frac{\P P_{t+1}}{\P R_{t+1}}\right\} = -\left(g_t + l_t^D\right)\frac{\P P_t}{\P R_t} - \left(g_t + l_t^D\right)\frac{\P P_t}{\P K_t}\,.$$

Towards an empirical implementation, the expectations term will be replaced by observables and a rational expectations error. Expectations E_t are formed over future prices, technologies, and interest rates on the basis of information available at the beginning of period *t*.

To obtain an empirically useful specification, several other functional form assumptions are necessary. The adjustment cost function is specified as

(A.16) $$G(I_t, R_t, C_t, K_t) = \frac{b^C}{2}\left[\frac{I_t}{C_t} - \nu^C\right]^2 C_t + \frac{b^K}{2}\left[\frac{R_t}{K_t} - \nu^K\right]^2 K_t$$

which is linearly homogeneous in its arguments. Additive separability is a matter of convenience here, since one may very well construct cases in which interaction between physical capital and R&D capital could matter. The output price p_t depends on the volume of output in order to allow for imperfect competition, i.e. $p_t = Y_t^{-1/\varepsilon}$ where ε is the price elasticity of demand and Y=F-G is net output. Then the profit derivatives of the firm's profit with respect to investment and capital stock are given by

$$\text{(A.17)} \qquad \frac{\partial \Pi_t}{\partial I_t} = -b^C \mu\, p_t \frac{I_t}{C_t} + b^C \nu^C \mu\, p_t - p_t^I$$

$$\text{(A.18)} \qquad \frac{\partial \Pi_t}{\partial C_t} = \mu\, p_t \left(\frac{\partial F}{\partial C_t} - \frac{\partial G}{\partial C_t} \right)$$

where $\mu = (1 - 1/\varepsilon)$. The expressions for R&D are analogous. We still have to find an operationalization for the marginal terms in equation (A.18). Note that both gross output F and adjustment costs G are homogeneous of degree one. Let $\varphi^C = (\partial Y / \partial C_t)(C_t / Y_t)$ denote the elasticity of net output with respect to physical capital. Taking account of the functional form specification for adjustment costs and of the first-order condition for the optimal allocation of variable factors L we can show that

$$\text{(A.19)} \qquad \frac{\partial \Pi_t}{\partial C_t} = \mu\, p_t \left((1 - \varphi^K) \frac{Y}{C_t} - \frac{1}{\mu p_t} \frac{w L_t}{C_t} + b^K \left(\frac{R_t}{C_t} \right)^2 - b^K \nu^K \frac{R_t}{C_t} + b^C \left(\frac{I_t}{C_t} \right)^2 - b^C \nu^C \frac{I_t}{C_t} \right)$$

Again, the R&D equation is analogous. Under the *null hypothesis* of no financing constraints and time-invariant tax regimes, the derived expressions can be used to obtain the following equation:

$$\text{(A.20)} \qquad \begin{aligned} -(1 - \delta^I)\beta_{t+1}^t E_t \left\{ -b^C \mu\, p_{t+1} \frac{I_{t+1}}{C_{t+1}} + b^C \nu^C \mu\, p_{t+1} - p_{t+1}^I \right\} = \\ -\left(-b^C \mu\, p_t \frac{I_t}{C_t} + b^C \nu^C \mu\, p_t - p_t^I \right) - \\ \mu\, p_t \left((1 - \varphi^K) \frac{Y}{C_t} - \frac{1}{\mu\, p_t} \frac{w L_t}{C_t} + b^K \left(\frac{R_t}{C_t} \right)^2 - b^K \nu^K \frac{R_t}{C_t} + b^C \left(\frac{I_t}{C_t} \right)^2 - b^C \nu^C \frac{I_t}{C_t} \right) \end{aligned}$$

Replacing the expectations operator by a rational expectations error term and collecting terms we have:

$$\text{(A.21)} \qquad \begin{aligned} \frac{I_{t+1}}{C_{t+1}} = n^C (1 - f_{t+1}^C) + (1 + n^C) f_{t+1}^C \left(\frac{I_t}{C_t} \right) - f_{t+1}^C \left(\frac{I_t}{C_t} \right)^2 - \frac{f_{t+1}^C}{m b^C} \left(\frac{X_t}{C_t} \right) \\ + \frac{f_{t+1}^C}{b^C} \frac{(1 + j^K (e - 1))}{(e - 1)} \left(\frac{Y_t}{C_t} \right) + \frac{b^K n^K}{b^C n^C} f_{t+1}^C \left(\frac{R_t}{C_t} \right) - \frac{b^K}{b^C} f_{t+1}^C \left(\frac{R_t}{C_t} \right)^2 + \frac{f_{t+1}^C}{m b^C} J_t^C + y_{it}^I \end{aligned}$$

where

(A.22) $$\phi^{C}_{t+1} = \frac{p_t(1+r_{t+1})}{p_{t+1}(1-\delta^{C})}$$

which will be greater than one for realistic values of the variables. The ratio of gross profit to capital, evaluated in real terms, is given by $(X_t/C_t) = (p_t Y_t - w_t L_t)/p_t K_t$. The user costs of physical capital are captured in

(A.23) $$J^{C}_{t} = \left(1 - \frac{p^{I}_{t+1}(1-\delta^{I})}{(1+r_t)p^{I}_{t}}\right)\frac{p^{I}_{t}}{p_t} .$$

This term will not be included explicitly, since price and depreciation data are not available at the firm level. The user cost term is simply captured by firm-specific effects and time dummies. The empirical specification for the investment equation under the null hypothesis of no financing constraints is thus given by

(A.24) $$\left(\frac{I}{C}\right)_{t+1} = b^{I}_{1}\left(\frac{I}{C}\right)_{t} + b^{I}_{2}\left(\frac{I}{C}\right)^{2}_{t} + b^{I}_{3}\left(\frac{X}{C}\right)_{t} + b^{I}_{4}\left(\frac{Y}{C}\right)_{t} + b^{I}_{5}\left(\frac{R}{C}\right)_{t} + b^{I}_{6}\left(\frac{R}{C}\right)^{2}_{t} + a^{I}_{t} + a^{I}_{i} + y^{I}_{it} .$$

Analogously, one can derive the empirical equation for the firm's R&D spending

(A.25) $$\left(\frac{R}{K}\right)_{t+1} = b^{R}_{1}\left(\frac{R}{K}\right)_{t} + b^{R}_{2}\left(\frac{R}{K}\right)^{2}_{t} + b^{R}_{3}\left(\frac{X}{K}\right)_{t} + b^{R}_{4}\left(\frac{Y}{K}\right)_{t} + b^{R}_{5}\left(\frac{I}{K}\right)_{t} + b^{R}_{6}\left(\frac{I}{K}\right)^{2}_{t} + a^{R}_{t} + a^{R}_{i} + y^{R}_{it}$$

The coefficients should - under the null hypothesis - satisfy the restrictions $\beta_1 > 1$, $\beta_2 < -1$, $\beta_3 < 0$, $\beta_4 > 0$, $\beta_5 > 0$, and $\beta_6 < 0$ where superscripts have been neglected, since these restrictions apply to both equations symmetrically.