No. 2056

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INDUSTRIAL ORGANIZATION

Centre for Economic Policy Research

ISSN 0265-8003

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Discussion Paper No.2056
January 1999

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CEPR Discussion Paper No. 2056

January 1999

ABSTRACT

Does Science Make a Difference? Investment, Finance and Corporate Governance in German Industries*

This paper examines the impact of industry knowledge conditions and corporate governance structures on tangible investment and its financing. Based on a large panel data set of German firms we investigate whether liquidity constraints vary systematically across firms engaged in activities reflecting very different knowledge conditions. In particular, we compare the extent of liquidity constraints in science-based firms with non science-based firms. This distinction is important because science-based firms generally fit the characteristics of market failure identified by Kenneth Arrow. Science-based economic activity is subject to high uncertainty, asymmetric knowledge and non-exclusiveness so liquidity constraints might be severe. Surprisingly, science seems to make a difference in that firms in science-based industries are less liquidity constrained than are their non science-based counterparts. In fact, the larger science-based firms do not seem to face liquidity constraints at all. However, governance structures play an important role. After accounting for the mode of corporate governance, we observe that the owner-controlled but not the manager-controlled firms are significantly liquidity constrained.

JEL Classification: G3, L2, O31
Keywords:determinants of investment, corporate governance

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Submitted 11 January 1999

NON-TECHNICAL SUMMARY

One of the greatest impediments to firm growth is a lack of finance. While many economists originally thought that capital markets operate efficiently, there is considerable anecdotal evidence suggesting that in fact, firms are subject to what has become known as *liquidity constraints*. Concern about the prevalence and impact of liquidity constraints led Alan S Blinder, who served on the Council of Economic Advisors under the Clinton Administration and as Vice-Chairman of the Federal Reserve Board of Governors, to lament, 'A few years ago, in revising my graduate course reading list, I looked for some modern literature on liquidity constraints and investment. There was none.' Scholars responded to Blinder's plea with a series of compelling studies providing convincing evidence that liquidity constraints not only exist but that they vary according to the characteristics of the firm. While a theoretical literature has emerged arguing that the core reason for financing constraints is uncertainty and asymmetric information, however, empirical studies have not systematically examined whether the degree to which liquidity constraints exist varies across industries characterized by different degrees of uncertainty and knowledge asymmetries.

The purpose of this paper is to examine whether the degree of liquidity constraints varies systematically across firms engaged in activities reflecting very different knowledge conditions. In particular, we compare the extent of liquidity constraints in science-based firms with non-science-based firms. This distinction is important because science-based firms generally fit the characteristics of market failure in that they are based on economic activity, which is uncertain, characterized by asymmetric knowledge and non-exclusive.

To estimate if the liquidity constraints of science-based firms differ from non-science-based firms, we apply a data set of 344 German firms from the mining and manufacturing industries. The firms come from 30 different two-digit industries (SYPRO). Most of these companies have the legal form of stock corporations (*Aktiengesellschaften*); 177 of them are quoted on German stock exchanges. In addition to stock corporations, we have also some limited liability corporations (GmbH companies), as well as limited commercial partnerships, for which balance sheet data were available. Balance sheet data are taken from the annual reports of the firms, while secondary sources were consulted for identifying owners, share distribution, composition of managing and supervisory boards. Annual observations are available for each firm between 1991 and 1996, making it possible to construct a panel data set.

The empirical evidence does suggest that governance structures play an important role. After accounting for the mode of corporate governance, we observe that the owner-controlled but not the manager-controlled firms are significantly liquidity constrained.

In addition, the results suggest that the most widely-used measures of liquidity constraints – the impact of cash flow and working capital on investment – have in fact a greater effect on external finance in non-science-based firms than in science-based firms While these results are surprising, they support the view that cash flow may serve a dual role for firms in science-based industries. Cash flow provides a source of internal finance, as has been traditionally recognized, but it also reflects a positive performance by the particular firm in industries where the underlying knowledge conditions are inherently uncertain, asymmetric and non-exclusive. Thus, cash flow in science-based industries serves as a signal for external investors that the particular firm has demonstrated success by generating internal funds.

The conventional view holds that finance is a prerequisite to science, which in turn breeds success. The findings in this study suggest something quite different, however: science fosters success and success breeds finance.

1 Introduction

One of the reasons why the determinants of firm investment remain ambiguous is that, "The investment literature has been schizophrenic concerning the role of financial structure and liquidity constraints" (Chirinko, 1993, p. 1902). From the perspective of the neoclassical model of the firm, a firm's investment decisions are independent of capital structure choice (except for tax considerations). Perfect capital markets guarantee all firms equal access to external finance. Any desired investment project with positive net present value can be financed either internally or externally, since external funds can costlessly substitute for internal capital (Modigliani and Miller, 1958). The assumption of perfect capital markets has, of course, been rigorously challenged. Just within several decades tremendous advances have been made regarding knowledge about the functioning of capital markets. A wave of theoretical studies argued that capital markets are different from other markets because of the roles that risk, uncertainty, and asymmetric information play.[1] Due to capital market imperfections arising from asymmetric information firms may face financing constraints for investment rather than having unlimited access to external finance. Once capital markets are no longer assumed to be perfect, external finance can also no longer be a perfect substitute for internal capital. One implication of this "new theory of the firm" (Greenwald and Stiglitz, 1990) is that financial factors, such as the reservoir of internally generated funds and the availability of new debt or equity, determine firm investment decisions.[2]

Scholars responded to the theories predicting liquidity to be constrained with a wave of empirical studies.[3] Almost all of the recent empirical work has followed the seminal article by Fazzari et al.

(1988), who linked firm-specific characteristics to the impact of cash flow on investment. Using *a priori* reasoning firms are classified into the subsets of unconstrained and potentially financing constrained firms on the basis of firm-specific factors, such as dividend payouts or firm size. The existence of liquidity constraints is then inferred from investment-cash-flow regressions by comparing the regression coefficients of cash flow across the two subsets. Changes in cash flow should not affect the investment spending of financially unconstrained firms. A regression coefficient that equals zero is thus interpreted as indicating perfect access to capital markets. By contrast, if capital markets are imperfect, cash flow should matter for the firms classified as potentially constrained. A regression coefficient that is significantly greater than zero is interpreted as indicating that external finance is not a perfect substitute for internal finance, and therefore that firms are liquidity constrained. Applying this approach, a growing literature provides compelling empirical evidence that liquidity constraints are

(1) systematically linked to firm-specific characteristics,
(2) most pronounced under unfavorable macroeconomic conditions (business cycle downturns), and
(3) more pronounced for the market-oriented Anglo-American financial system.[4]

However, virtually no study has focused on the role that the industry environment plays in liquidity constraints. As Arrow (1962) pointed out in his seminal article, the knowledge conditions underlying an industry vary systematically across industries and may crucially affect investment. In some industries innovation depends more on basic scientific knowledge and systematic R&D than in others. Science-based industries generally fit the characteristics of market failure identified by Arrow (1962) in that economic activity is particularly subjected to uncertainty, asymmetric information and problems of appropriating the returns from investment based on newly created knowledge. Firm investment in science-based industries may thus be more constrained by the availability of internal and external finance than in industries where knowledge is relatively certain and symmetric. The purpose of this paper is to examine whether the presence and the degree of liquidity constraints is linked to industry knowledge conditions. Further, since asymmetric information can be reduced by appropriate governance mechanisms, we investigate the impact of corporate governance structures on the investment-cash flow relationship while controlling for knowledge conditions and firm size. Based on a large panel data set of German firms we find evidence suggesting that science by itself as well as in combination with the mode of governance and firm size does make a difference. However, the way in which it does is surprising. Finally, focusing on firms that operate in a bank- or network-oriented financial system like in Germany allows us to add empirical insight to the current debate on comparative advantages of financial sytems for firm investment.

2 Why Should Science Make A Difference?

Why should science make a difference? Stephan (1996) and Dasgupta and David (1994) argue that firms engaging in science-based activities are typically associated with a greater degree of uncertainty, or *hyper-uncertainty*, and *hyper-knowledge asymmetries* about the potential economic value of their investments. As Arrow (1962) emphasizes, more than most other economic goods, the production of new economic knowledge generally suffers from three sources constituting market failure – indivisibilities and monopoly, uncertainty, and externalities.

The first source of market failure emanates from the propensity for knowledge to be a discrete rather than a continuous commodity. As a result, both economies of scale and scope are often associated with the production of knowledge (Mueller and Tilton, 1969). The second source of market failure involves the extraordinarily high degree of uncertainty inherent in new economic knowledge. While virtually every economic good is subject to uncertainty, almost none is exposed to the degree of risk involved in science-based new technologies. There are two additional elements of uncertainty that are specific to innovative activity. The first is in the realm of production. How a new good can be technically produced is typically shrouded in uncertainty. The second involves marketing the product. Whether a demand for the new product exists is not known. Even if the knowledge can result in a new product, it is not at all clear that the product can be profitably sold. Knowledge leading to a new economic good can be produced, but there is no guarantee that the new knowledge will be economic knowledge. The third source of market failure stems from the public good nature and non-exclusive externalities inherent in science-based economic activity. It is difficult to delineate and enforce property rights to newly created knowledge. Knowledge may "spill over" so that other economic agents cannot fully be precluded from applying that knowledge for economic gain.

The externalities associated with the production of new knowledge make it difficult for firms undertaking such activities to appropriate the economic returns accruing from their investment. Since firms engaged in science-based activity are subject to *hyper-uncertainty, hyper- knowledge asymmetries*, as well as *appropriability* problems it might be expected that they experience a greater degree of liquidity constraints imposed upon them by traditional lending institutions than do non-science based firms. This would predict an even greater regression coefficient of cash flow on investment.

However, there are compelling reasons to suspect that in science-based firms cash flow serves a second and crucial economic function – as a signal of the firm's viability and success. The theory of noisy selection introduced by Jovanovic (1982) argues that new firms do not know whether the idea upon which their new firm is launched is viable in the market or not. Rather, they discover the viability of the idea through the process of learning from the firm's actual post-entry performance. By analogy, as a result of the hyper-uncertainty, hyper-knowledge asymmetries, and potential non-exclusive nature of a science-based firm's investment activities, it is more difficult to evaluate the expected value of a science-based firm than a non science-based firm. The generation of cash flow in a highly uncertain environment, however, does signal firm success and viability. As Arrow (1962) and later Sah and Stiglitz (1986) argue, the cost of acquiring a signal to learn about the underlying economic performance in the presence of uncertain, asymmetric knowledge is nontrivial. Thus, by serving as a signal that the firm is being positively selected in the market process, cash flow may actually make it easier to attract external finance. The dual function of cash flow in science-based firms leads us to predict that the impact of cash flow on investment will actually be weaker in science-based firms, due to the signaling effect of cash flow.

The underlying knowledge conditions should matter more for small and new science-based firms than for their larger, more established counterparts (Audretsch, 1995). Larger firms tend to be older, more diversified and more established in product markets than smaller firms, allowing for a more stable cash flow to avoid being subjected to financing constraints. Access to external finance should be easier for larger firms because they generally own more resalable fixed assets to be used as collateral, have a longer track record (credit reputation), and can take advantage of established informal relations to capital providers. We would thus expect that the signaling effect is more important for small firms, or, put differently, operating in a science-based environment may outweigh disadvantages of small size and alleviate size-related financing problems.

3 Corporate Governance and Investment

A second important direction of the literature has been devoted towards identifying the impact of corporate governance on capital structure choice and firm performance.[5] Corporate governance, which basically addresses the alignment of interests of a firm's owners, managers and stakeholders (e.g. creditors, employees), does not matter in the neoclassical theory of the firm. Both utility maximization by an owner-manager and maximization of shareholder value by hired managers lead to the same Pareto-optimal allocation of the firm's resources. However, with asymmetric information prevailing objectives and incentives of managers, shareholders and stakeholders do not coincide automatically but governance mechanisms are called for to align interests.

Conflicts of interests affecting investment decisions may arise from the separation of ownership and control in diffusely held companies when the ultimate owners only have small equity interests and control over the firm is delegated to hired managers and honorary outside supervisors. As a consequence of separating control from ownership, managerial investment decisions may reflect managers' personal interests rather than those of shareholders or creditors. In "manager-controlled" companies hired managers may be able to divert free cash flow for pet projects, perks etc. (see, e.g., Jensen, 1986). It has been argued in the governance literature that the presence of large shareholders (ownership concentration), direct involvement of owners in leading and controlling a firm (board representation), and banks (as monitoring creditors or equity holders) may provide efficient and effective governance, facilitating access to external finance and boosting investment. Large blockholdings and board representation of large shareholders may signal "owner-control", that is, the owner's close involvement in leading and controlling a company. Large “inside” shareholders may be better informed and thus able to reduce agency conflicts with hired managers or external capital providers. If they have sufficient control over the firm’s assets, such as a blocking interest, large shareholders can actually govern by exercising their voting rights. Since they aim at maximizing their return on investment, they have a strong interest in the selection of top-level managers, monitoring their progress, and intervening when they fail. Banks as large creditors may have a similar controlling influence like large shareholders. Their governance role might be even stronger in a bank-oriented financial system like Germany where banks are allowed to hold equity stakes in industrial firms and exercise proxy voting rights. The mode of corporate governance may thus affect liquidity constraints if tighter governance reduces the transaction cost and agency costs associated with knowledge asymmetries.

There may also be costs involved with large investors. For example, the interests of large shareholders need not coincide with the interests of other investors in the firm, thus leading to an inefficient redistribution of wealth.[6] Banks could exploit an exclusive main-bank relationship and charge its client firm a higher interest rate or limit the use of debt by covenants, that is, make the firm more financially constrained (Sharpe, 1990; Rajan, 1992). In sum, how corporate governance structures affect firm investment is an empirical question.

Only a few studies have focused on the impact of governance structures on investment.[7] Holderness and Sheehan (1988) found no significant differences in tangible and intangible investment patterns between majority-held and diffusely owned U.S. companies. Also Cho (1998), using a sample of large U.S. manufacturing firms (from Fortune 500), reports evidence that ownership structure does not impact on tangible and R&D investment. He finds instead that investment affects corporate value, which in turn has an impact on ownership structures. This result is not too surprising, since in the strongly stock market-oriented U.S. financial system changes in ownership structures are rather common and ownership concentration tends to be extremely low on average. Firms undertaking profitable investments attract new investors and the highly liquid U.S. stock markets guarantee that shares can be easily purchased and sold.

Things may be different in the network- or bank-oriented German financial system where stock market capitalization is low, industrial ownership is highly concentrated, and banks maintain close relations with non-financial firms. Many small and medium-sized firms are completely family property. Only some of the very large traded stock corporations have widely dispersed outside shareholdings. Further, ownership structures of most firms are observed to remain unchanged for many years. Elston and Albach (1995) and Bond et al. (1997) investigate whether having banks as (co-)owners of industrial firms is a governance mechanism in Germany that alleviates liquidity constraints. Comparing the investment-cash flow link between bank-owned and non bank-owned firms they find that the non-bank affiliated firms tend to experience greater liquidity constraints.

The impact of the mode of governance on the presence of financing constraints may have more relevance for smaller independent firms than for large firms or small subsidiaries of large firms. There is sound empirical evidence that the degree of liquidity constraints is negatively related to firm size (see Fazzari et al., 1988). In particular, small owner-managed firms in R&D-intensive environments seem to suffer most (see Himmerlberg and Petersen, 1994). Having a large corporation as main shareholder may provide substantial backup finance and collateral for the investment of a small firm. However, the results in Lang and Stulz (1994) as well as Shin and Stulz (1998) imply that subsidiaries may be liquidity constrained. They report that diversified large US firms did not channel internal funds efficiently into those segments with the best investment opportunities.

If the mode of governance affects the extent of knowledge asymmetries and thus the financing of firm investment we would expect the impact of corporate governance to be more pronounced in science-based industries and for smaller firms.

4 Measurement

The data

To estimate if the liquidity constraints of science-based firms differ from non science-based firms and how governance structures and firm size link in, we apply a data set of 361 German firms, which come from 27 different mining and manufacturing industries (two-digit SYPRO industry classification). Most of the sample firms have the legal form of stock corporation (*Aktiengesellschaft*); 182 of them are quoted on German stock exchanges. In addition to stock corporations, we have also some private limited companies (GmbH companies), as well as limited partnerships, for which accounting data were available. Accounting data for constructing empirical variables were taken from the firms' annual reports, while secondary sources had to be consulted for identifying owners, distributions of shares outstanding, composition of managing and supervisory boards.[8] Annual observations were available for each firm between 1991 and 1996, making it possible to construct a panel data set.

Defining subgroups of firms

Our classification of industries as being science-based or not is based on survey results reported in Beise and Licht (1996, pp. 4-6, Tables 2.1 and 2.2).[9] The survey reveals that chemicals (including pharmaceuticals and biotechnology), machinery, motor vehicles, electronics (including information technology), and instruments (including laser technology, cameras, watches and clocks) had the highest R&D intensities and the highest share of firms with R&D budgets and in-house R&D laboratories. Further, economic activities in these industries are specifically based on knowledge generated in the natural sciences. Therefore, we define these industries as well as the aerospace industry, which is not listed separately in Beise and Licht, as *science-based*. All other industries are regarded as *non* (or, less) *science-based*. Table 1 shows industries, classifications and the distribution of our sample firms. According to their dominant economic activity we classified 223 firms into science-based and 138 into non science-based industries.

[Table 1 about here]

A striking feature of the ownership structure of German firms is the presence of very large shareholders and a high level of ownership concentration. As Table 2 shows, more than two-thirds of the sample firms had just one large shareholder who, on average, commanded a dominating share of the voting capital. Only in 71 firms the largest shareholder did not have at least a majority block of the voting capital. Further, owners and ownership concentration barely change over time. We identified 26 firms that had changes in owners and a turnover of blockholdings during the sample period. Only 6 per cent of the variation of ownership concentration in our sample results from time series (within) variation, while 96 per cent is attributable to variation across firms (between variation).

[Table 2 about here]

Since ownership is so highly concentrated for an overwhelming part of our sample firms and has so little time series variation, we capture the mode of governance by distinguishing between manager-controlled and owner-controlled firms. We define a firm as owner-controlled if individuals, families or banks have equity stakes (or accumulated proxy voting rights in the case of banks) exceeding at least 5% of the voting capital and there is no independent company identifiable that commands a *larger* share. All other firms with no identifiable large shareholder or with an another industrial company as large shareholder are defined as manager-controlled. For these manager-controlled firms we assume that it is hired managers rather than the ultimate owners who exercise control. About 40 per cent of the sample firms are owner-controlled. In most of these firms owners are represented on either the management board or the board of supervisors, sometimes on both.[10]

To compare small and large firms, we define small firms as having less than 500 employees during the observation period. The definition of a small firm as having 500 employees or less, while confirming to government definitions, is arbitrary but unavoidable here because smaller firms are underrepresented in our sample. However, due to the fact that only stock corporations and larger private limited companies are obliged by German law to publish financial statements this shortcoming cannot be overcome easily. Nevertheless future work should examine how the determinants of liquidity constraints vary systematically as firm size changes.

Regression models and hypotheses

We estimate the regression model:

(1) $$\frac{I_{it}}{A_{it-1}} = \beta_1 \frac{CF_{it}}{A_{it-1}} + \beta_2 \frac{S_{it}}{A_{it-1}} + \beta_3 \frac{\Delta_t WC_i}{A_{it-1}} + \beta_4 \frac{\Delta_t LTD_i}{A_{it-1}} + \beta_5 \frac{\Delta_t PL_i}{A_{it-1}} + \mu_{it} .$$

The subscripts *i* and *t* denote individual firms and time periods respectively, Δ is the first-difference operator. *I* is a firm's current expenditures for tangible investment. We use the beginning-of-the year book value of total assets, *A*, as a scaling factor.[11] *CF* denotes cash flow (operating income plus depreciation charges plus the year-to-year change in liability reserves), *S* current sales, Δ *WC*, Δ *LTD* and Δ *PL* the year-to-year changes in net working capital (current assets minus current liabilities), long-term debt *LTD* and pension liabilities *PL* respectively.

To allow for unobserved heterogeneity across firms and time periods because of systematic variations in the user cost of capital or bias due to the non-random character of sample selection we assume the error term μ_{it} to be represented by

(2) $$\mu_{it} = \alpha_i + \lambda_t + \nu_{it} ,$$

where α_i are fixed (time-invariant) firm-specific parameters, λ_t refer to time-specific (firm-invariant) effects and ν_{it} ~iid $(0, \sigma_\nu^2)$ denote white noise disturbances.

The impact of cash flow on investment is reflected by the coefficient β_1. With imperfect capital markets, we would expect that $\beta_1 > 0$ if investment opportunities were properly controlled for.

Many studies in the literature control for investment opportunities by including Tobin's Q in the estimating equation. Unfortunately, in this study Tobin's Q cannot be constructed because of the relatively large number of non-quoted firms (179) in our sample. In order to control for investment opportunities, we instead use the sales-to-total assets ratio which indicates the utilization of a firm's total assets and thus the need for additional investment (see Brealey and Myers, 1984, p. 574). We would expect $\beta_2 > 0$.

An important qualification is that these proxy measures may introduce measurement bias. Studies have identified average Tobin's *Q* as well as the sales-to-assets ratio or sales growth as being less than perfect indicators of investment opportunities.[12] To the extent that the regression coefficient is biased, a positive estimated coefficient of cash flow may then simply indicate shifts in investment demand and future profitability and not necessarily that firms are financially constrained. Different solutions, such as estimating the Euler equation, accelerator or error-correction models, have been suggested in the literature to overcome these measurement problems. However, these approaches often call for rather long time series data, since the estimation techniques for dynamic panel data models (e.g. GMM) consume a substantial amount of degrees of freedom.[13] A solution to identifying the potential liquidity role of cash flow, which is feasible for a short panel data set like ours, was suggested by Fazzari and Petersen (1993). They point out that a firm confronted by liquidity constraints typically adjusts net working capital to smooth investment relative to cash flow shocks if adjusting tangible or R&D investment entails higher costs than adjusting the difference between current assets (cash, short-term securities, receivables, inventories) and current liabilities. They recommend including the change in net working capital to separate the profitability indicating part of cash flow from its liquidity role. Therefore, for a financially constrained firm, we would expect an inverse relationship between investment and the change in net working capital, $\beta_3 < 0$. However, if cash flow signals investment opportunities rather than liquidity, we should also observe a positive coefficient for the change in net working capital in the investment equation, $\beta_3 > 0$, since the change in net working capital tends to be positively correlated with profits or sales. Of course, as we assume that investment in tangible investment is financed from current cash flow, investment in net working capital is also an endogenous variable. To account for the simultaneity of tangible investment and net working capital investment we use two-stage least square estimation techniques (Within-2SLS), instrumenting the change in net working capital by the lagged working capital ratio plus all other right-hand side variables from regression equation (1).[14]

We include the changes in long-term debt and pension liabilities as indicators of firms' access to finance other than cash flow. It is often argued for the bank- or network-oriented German financial system that bank loans are more readily available than other forms of external finance because German banks may be well-informed and effective monitors due to close relationships to industrial firms (e.g. through equity holdings, proxy voting rights, board representation).[15] Although not reported separately by most firms in our sample, long-term debt presumably reflects bank loans to a substantial extent.[16] A peculiarity of the German accounting system is that pension assets and pension liabilities are not netted out in companies' balance sheets. Moreover, pension liabilities are not paid into a trust (pension fund) but remain within the firm and are available to the firm as a source of long-term finance. The availability of long-term debt or pension liabilities should not matter for investment with perfect capital markets, since capital structure does not affect investment spending and the choice of financing instruments (except for tax purposes). By contrast, if investment is not separable from finance because of capital market imperfections, agency and transaction costs render not only internal and external finance but also alternative instruments of external finance imperfect substitutes (Jensen and Meckling, 1976; Myers and Majluf, 1984). If German firms suffer from financing constraints despite the potential advantages of bank- or network-orientation we would expect the changes in long-term debt and pension liabilities to be positively related to investment, $\beta_4 > 0$ and $\beta_5 > 0$. In sum, for firms operating under a regime of financial constraints we should observe $\beta_1 > 0$, $\beta_2 > 0$, $\beta_3 < 0$, $\beta_4 > 0$ and $\beta_5 > 0$ to be statistically significant.

If knowledge conditions, the mode of governance, firm size, or combinations of these factors make a difference for the presence of liquidity constraints we would expect to observe differences in coefficients between subgroups of firms. To test for differences in the slope coefficients across subgroups of firms we estimate a variant of regression model (1), which additionally contains all right-hand side variables from (1) interacted with a dummy variable D_i

(3) $$\frac{I_{it}}{A_{it-1}} = \beta_1 \frac{CF_{it}}{A_{it-1}} + \delta_1 D_i \times \frac{CF_{it}}{A_{it-1}} + \beta_2 \frac{S_{it}}{A_{it-1}} + \delta_2 D_i \times \frac{S_{it}}{A_{it-1}} + \ldots + \mu_{it} .$$

To compare coefficients between the subgroups of science-based (manager-controlled, large) and non science-based (owner-controlled, small) firms we define $D_i = 1$ if firm *i* operates in science-based industry (is manager-controlled or small), $D_i = 0$ otherwise. The β coefficients then measure the impact of the respective variables on investment of the non science-based (owner-controlled, small) firms, whereas the δ coefficients measure the difference between the βs and the slope coefficients of the science-based firms. Adding δs to βs, or estimating the equation with the dummy variable defined the other way around, yields the slope coefficients for the science-based (manager-controlled, large) firms.[17] Finally, to examine potential interactive effects of knowledge conditions, the mode of corporate control and firm size on the extent of liquidity constraints, we combine these factors which yields eight subsets of firms: large manager-controlled firms in science-based industries (SML), large owner-controlled firms in science-based industries (SOL), small manager-controlled firms in science-based industries (SMS), small owner-controlled firms in science-based industries (SOS), large manager-controlled firms in non science-based industries (NML), large owner-controlled firms in non science-based industries (NOL), small manager-controlled firms in non science-based industries (NMS), and small owner-controlled firms in non science-based industries (NOS). By defining dummy variables for each subgroup, augmenting the regression model appropriately by the respective sets of interacted variables and changing the baseline subset of firms alternately we obtain the coefficient estimates for each subset and the coefficient differences for each pair of subsets.

5 Empirical Results

Descriptive statistics

Table 3 compares the means of selected firm variables between science-based and non science-based, manager-controlled and owner-controlled, as well as large and small firms. For each variable and pair of sub-groups we report the absolute t-statistics of testing for differences in means.[18]

[Table 3 about here]

As measured by sales and employment, science-based, owner-controlled and, of course, larger firms are significantly larger than their counter-parts. The annual rate of change in employment was negative in all subgroups. However, employment downsizing was significantly less severe for the owner-controlled firms and for the small firms. The owner-controlled firms also experienced significantly higher rates of sales growth.

Science-based firms display significantly lower ratios of investment and cash flow but the sales-assets ratio is also lower, implying less opportunities for additional investments. This lower tangible investment ratio might reflect a greater emphasis of the science-based firms on R&D investment. Unfortunately, we cannot investigate R&D investment directly because data on firm-specific R&D expenses are not available for most of our sample firms. The net working capital ratio and their share of pension liabilities is significantly higher, whereas the ratio of long-term debt is lower. This pattern indicates that the science-based firms may be better able to smooth investment spending in the face of cash flow shocks by reducing net working capital and tapping the reservoir of funds build up to satisfy pension schemes. The lower long-term debt ratio may also reflect that firm investment in science-based industries is preferably financed internally because of higher uncertainty.

Owner-controlled firms have significantly higher ratios of investment and cash flow but the sales-assets ratio is also higher so that investment opportunities might not have been fully exploited. They rely more on long-term debt, and this ratio has increased significantly over the observation period. By contrast, their ratio of pension liabilities is significantly lower.

Large firms have significantly lower ratios of cash flow and net working capital than small firms but the sales-assets ratio is also significantly lower, indicating more exploited investment opportunities. They have a higher ratio of pension liabilities, and the ratio has increased significantly more over the observation period.

Regression results

The regression results from estimating model (1) for the full sample of firms and from model (3) considering differences in knowledge conditions, mode of governance and firm size are shown in Table 4.

[Table 4 about here]

The full sample estimates suggest that our sample firms were subject to liquidity constraints during the observation period. The coefficients of cash flow and of the sources of long-term capital are positive and statistically significant. In addition, the coefficient of the change in net working capital is significantly negative and the coefficient of the sales-to-assets ratio, controlling for investment opportunities, is significantly positive.[19] All these reults are consistent with the predicted pattern of coefficients in the presence of liquidity constraints Calculated at mean values (taken from Table 3), the elasticity of investment with respect to cash flow is 0.17 (0.16 at median values). Studies for the United States typically estimate comparable elasticities for financially constrained firms of 0.50 and greater (see, e.g., Fazzari et al., 1988; Himmelberg and Petersen, 1994). The year dummies pick up the downward trend in firm investment that set in after the German reunification boom 1990/91 and was aggravated by the 1993 recession, the most severe since the oil crises of the 1970s.

Differences in knowledge conditions seem to matter. The cash flow coefficient of the science-based firms is smaller but not significantly so. However, the non science-based firms smoothed tangible investment significantly more by adapting net working capital. The coefficient of the change in net working capital is highly significant as is the coefficient difference. Further, the availability of long-term debt is significantly more important for the non science-based firms. We may conclude that there is a statistically significant difference in the extent of liquidity constraints between science-based and non science-based firms. Thus, liquidity constraints are *less* severe in science-based industries. As Jovanovic's (1982) theory of noisy selection would predict, in an uncertain environment cash flow may serve to signal market success, facilitating access to external finance and making investment less depending on the availability of internal finance. After accounting for knowledge conditions, we find cash flow elasticities of 0.14 for the science-based firms and of 0.21 for the non science-based firms. The estimated coefficients on long-term debt imply that, at mean values, doubling the long-term debt ratio equals a 0.7 per cent increase in the investment ratio for science-based firms and a 1.4 per cent increase for non science-based firms.

Both manager- and owner-controlled firms show the coefficient pattern expected in the presence of liquidity constraints. Although the relevant coefficients tend to be smaller for the manager-controlled firms, there is no statistically significant difference between the two subgroups except for the coefficients of the sales-assets ratio. The difference indicates that the owner-controlled firms responded more to changes in investment opportunities. The corresponding elasticities are 1.15 versus 0.66.

In accordance with Anglo-Saxon studies we find small firms to be significantly more constrained than large firms. The small firms' cash flow elasticity at mean values is 0.48, which is very close to what Fazzari et al. (1988) report for non-dividend paying firms. The availability of long-term financing sources is significantly more important for the small firms.

Table 5 presents the results of testing for interactive effects of knowledge conditions, the mode of corporate control and firm size. The baseline group is the subset of large manager-controlled and science-based firms (SML). The coefficient estimates in column (1) cast considerable doubt on the presence of financing constraints for this subset of firms. The cash flow coefficient is indeed significantly positive but small. Moreover, the coefficients of the changes in net working capital, long-term debt and pension liabilities are clearly insignificant. Columns (2) to (8) contain the coefficient differences to the other subsets of firms. There are no significant differences for the large owner-controlled science-based firms (SOL) as well as the large manager-controlled firms from non science-based industries (NML). Most surprisingly, this is also true for the small owner-controlled firms in science-based industries (SOS). The cash flow coeffcients of these three subsets of firms are even slightly smaller than for the baseline group. The coefficient of the change in net working capital turns out to be even insignificantly positive for the SOS firms, implying that the investment-cash flow correlation reflects better investment opportunities rather than financing problems. As we have argued above, the generation of cash flow may signal to external financiers that a small but science-based firm is positively selected in the market process. Certainly, caution in interpretation is warranted because of the small number of firms in the small firm subsets.

Obvious differences exist with respect to the small manager-controlled firms in both science-based and non science-based industries (SMS, NMS) as well as the large and small owner-controlled firms in non science-based industries (NOL, NOS). These subsets of firms appear to be financially constrained. The cash flow coefficients with the exception of the small owner-controlled firms (NOS) and all coefficients of the change in long-term debt are significantly larger than for the baseline group. Even if the cash flow coefficient for the small owner-controlled firms in the non science-based industries is very small, the highly significant and large differences of all other coefficients suggests the presence of financing constraints. Table 6 summarizes the results by listing the estimated cash flow elasticities for the eight subsets of firms as well as some performance measures. The small manager-controlled firms have by far the highest cash flow elasticities but also have fairly high gross returns on total assets, measured as current sales revenues minus outlays for personel and materials scaled by the end-of-the-period book value of total assets. However, a look at sales growth and the change in costs and employment reveals that profitability was mainly generated by cutting costs and reducing employment. All other firms except for the the small owner-controlled firms in science-based industries reduced employment as well. By contrast, these small owner-controlled firms in science-based industries which we find not to be financially constrained have the lowest return on total assets but by far the highest sales growth and, most strikingly given the recessive observation period, a large positive increase in employment. However, outlays for personnel and materials increased correspondingly so that the gross profit was squeezed.

6 Conclusions

Since Alan S. Blinder (1988, p. 196) lamented, “A few years ago, in revising my graduate course reading list, I looked for some modern literature on liquidity constraints and investment. There was none,” scholars have responded with a series of compelling studies providing convincing evidence that liquidity constraints exist and that they vary according to the characteristics of the firm. While a theoretical literature has emerged arguing that the core reason for financing constraints is uncertainty and asymmetric information, however, empirical studies have not systematically examined whether the degree to which liquidity constraints exist vary across industries characterized by different degrees of uncertainty and knowledge asymmetries.

In this paper we have explicitly focused on how financing constraints vary according to the knowledge conditions underlying industries, the mode of governance and firm size. In particular, we compared the extent of liquidity constraints between firms from science-based and non science-based industries. Science-based firms are characterized by the three types of market failure identified by Arrow, and would be expected to experience a greater degree of financing constraints. Surprisingly, the evidence on the impact of cash flow on investment suggests that the extent of liquidity constraints is significantly *smaller* for the science-based firms. Further, two firm characteristics, the mode of governance and firm size, play a crucial role as determinants of investment and the degree of liquidity constraints. Consistent with Anglo-Saxon studies, we find small firms to be more constrained than large firms. However, science in combination with the mode of governance makes a difference in that the small owner-controlled firms in the science-based industries do not seem to be constrained at all. This also is true for both the large manager-controlled and owner-controlled firms. The small owner-controlled firms from the science-based industries are clearly *less* constrained than either the small manager-controlled firms in both science-based and non science-based industries or the owner-controlled firms from non science-based industries. Despite a larger potential for knowledge asymmetries science-based industries may provide a better environment than non science-based industries for small firms to demonstrate entrepreneurial skill and excellence, to grow by continuously investing in innovation, and to attract external capital (Audretsch, 1995). The ability to generate cash flow secures not just a source of finance but also signals market success and viability. For an owner-controlled small firm, survival under conditions of hyper-asymmetries and -uncertainty may amplify the cash flow signal to capital providers external to the firm and alleviate the access to external finance.

Taken together and compared to the empirical evidence from Anglo-American firm data, our results concerning the cash flow elasticity of tangible investment imply that at most only modest liquidity constraints exist in Germany. However, an important qualification for these findings is that the inferences and interpretations are based on a “truncated” non-random sample excluding the smallest-sized firms. The inherent data restrictions, such as unavoidable survivor bias may extenuate the efficiency of firm financing in the German financial system. Nonetheless, from our viewpoint, the findings in this study have two major implications. First, the link between investment and finance may be more intricate than previous empirical studies imply. It is the interplay between industry characteristics, firm size, and governance structures that influences firm investment activities and determines the extent of liquidity constraints. Second, the conventional view holds that finance is a prerequisite to science-based economic activities but that finance may be severely constrained, particularly for new and small firms, because science-based activities are subject to hyper-uncertainty and hyper-knowledge asymmetries. Therefore, firm investment in science-based industries may be sub-optimal and limited to large firms, since small and new firms suffer from financing disadvantages. The results presented in this paper suggest something different: science-based industries may offer more windows of opportunities for new and smaller firms than non science-based industries. Science-based economic activities thus foster entrepreneurial success, and entrepreneurial success in turn breeds finance for investment.

Table 1 Distribution of Sample Firms and Industry Characteristics

Industry	R&D intensity * (in %)	Firms with R&D ** (in %)	Number of sample firms
Science-based industries			223
Chemicals and allied products	8.1	57	60
Electric and electronic equipment	6.0	63	56
Motor vehicles and allied products	5.3	40	18
Instruments and related products	5.1	41	10
Machinery, except electrical	3.3	44	76
Aircraft and aerospace technologies	n.a.	n.a.	3
Other industries			138
Steel and light metal construction	2.9	9	4
Leather and leather products, textile mill products, apparel	1.9	25	3
Rubber and plastic products	1.6	45	4
Primary metal industries	1.1	30	37
Fabricated metal products	0.9	37	16
Lumber, paper, printing, and allied products	0.9	12	4
Stone and clay, pottery and glass products	0.8	17	33
Food and kindred products, tobacco manufacturers	0.6	7	4
Other manufacturing	n.a.	n.a.	33

Notes:

* total expenditures for R&D and innovation in 1993 in per cent of sales revenues, source: Beise and Licht (1996), based on the ZEW innovation survey (Mannheimer Innovationspanel, Zentrum für Europäische Wirtschaftsforschung), including 43,300 West German firms.

** in per cent of all reporting firms, source: Beise and Licht (1996).

Table 2 Ownership Structure of the Sample Firms

Number of large shareholders (more than 5% of voting capital)	Number of firms	Mean (st.dev.) of largest shareholder's share in voting capital (in per cent)	Mean (st.dev.) share of dispersed ownership (in per cent)	Number of owner-controlled firms
0	6	0.55 (1.35)	99.45 (1.39)	0
1	243	87.34 (23.18)	10.01 (19.13)	105
2	65	55.65 (16.21)	16.84 (17.52)	25
3	28	44.43 (18.33)	24.68 (23.56)	5
> 3	19	55.58 (28.28)	21.23 (24.73)	8
Overall	361	75.19 (28.78)	14.45 (22.76)	143

Voting power of the largest shareholder	Number of firms	Mean (st.dev.) of largest share-holder's share in voting capital (in per cent)
Minority interest	27	11.72 (9.89)
Blocking interest	44	39.67 (8.80)
Majority interest	77	59.57 (7.84)
Dominating interest	213	96.22 (7.00)

Definitions:

Minority interest	less than 25.0 per cent of voting capital
Blocking interest	between 25 per cent of voting capital plus one vote and 50.0 per cent of voting capital
Majority interest	between 50 per cent of voting capital plus one vote and 75.0 per cent of voting capital
Dominating interest	75 per cent of voting capital plus one vote and more

Table 3 *Summary Statistics 1991-1996*

Variable	Mean (standard error)			
(as defined in the text and in per cent if not otherwise noted)	All firms	Science-based Non science-based t-statistic (d.f.)	Manager-controlled Owner-controlled t-statistic (d.f.)	Large Small t-statistic (d.f.)
Investment ratio	7.61 (0.15)	6.76 (0.16) 8.98 (0.29) 6.73 *** (1125)	7.07 (0.15) 8.17 (0.1) 4.48 *** (1765)	7.71 (0.15) 7.14 (0.47) 1.16 (400)
Cash flow ratio	11.56 (0.27)	10.51 (0.32) 13.26 (0.47) 4.89 *** (1296)	10.40 (0.30) 12.39 (0.33) 4.48 *** (1974)	11.28 (0.28) 12.80 (0.71) 2.01 *** (441)
Sales-to-assets ratio	156.71 (1.76)	154.10 (2.21) 160.93 (2.91) 1.87 * (1420)	153.80 (2.41) 161.15 (2.51) 2.12 ** (1694)	153.46 (1.75) 171.25 (5.54) 3.06 *** (397)
Net working capital ratio	31.89 (0.46)	34.35 (0.59) 27.92 (0.70) 7.03 *** (1533)	31.95 (0.56) 32.21 (0.60) 0.73 (2000)	31.06 (0.47) 35.64 (0.13) 3.23 *** (413)
Δ *Net working capital ratio*	2.23 (0.35)	2.50 (0.47) 1.79 (0.50) 1.03 (1431)	1.12 (0.41) 0.61 (0.44) 0.81 (1670)	2.12 (0.90) 2.71 (0.38) 0.61 (450)
Long-term debt	11.70 (0.32)	10.75 (0.40) 13.23 (0.52) 3.76 *** (1440)	10.65 (0.43) 13.30 (0.46) 4.19 *** (1682)	11.94 (0.36) 10.65 (0.71) 1.61 (507)
Δ *Long-term debt*	0.50 (0.24)	0.52 (0.32) 0.49 (0.37) 0.06 (1563)	0.04 (0.33) 1.21 (0.35) 2.44 ** (1686)	0.56 (0.28) 0.26 (0.47) 0.56 (585)
Pension liabilities	28.30 (0.36)	29.52 (0.48) 26.31 (0.50) 4.61 *** (1671)	29.93 (0.47) 25.81 (0.54) 5.78 *** (1599)	29.52 (0.39) 22.84 (0.85) 7.14 *** (472)
Δ *Pension liabilities*	1.51 (0.13)	1.64 (0.17) 1.32 (0.21) 1.19 (1537)	1.54 (0.18) 1.48 (0.20) 0.22 (1614)	1.63 (0.15) 0.98 (0.28) 2.07 *** (540)
Sales (in millions DM)	3,316 (239)	3,820 (344) 2,502 (282) 2.96 *** (1799)	2,578 (189) 4,357 (457) 3.60 *** (1154)	4,020 (289) 171 (21) 13.30 *** (1488)
Sales growth (annual log change in real sales)	2.19 (0.53)	2.46 (0.67) 1.76 (0.88) 0.63 (1425)	0.93 (0.74) 4.23 (0.72) 3.18 *** (1737)	2.07 (0.59) 2.74 (1.26) 0.48 (480)
Employment	10,972 (803)	13,094 (1,217) 7,543 (719) 3.93 *** (1693)	7,940 (557) 15,824 (1,648) 4.53 *** (1053)	13,369 (972) 263 (8) 13.49 *** (1474)
Employment change (annual log change in total employment)	–1.96 (0.46)	–1.42 (0.55) –2.83 (0.80) 1.46 (1319)	–3.24 (0.53) –0.00 (0.82) 3.28 *** (1319)	–2.39 (0.48) –0.04 (1.26) 1.78 * (430)
Firms (pooled observations)	361 (1805)	223 (1115) 138 (690)	218 (1090) 143 (715)	295 (1475) 66 (330)

*, **, *** significant at the 0.10, 0.05, 0.01 level respectively

Table 4 *Investment and Finance: Knowledge Conditions, Corporate Governance and Firm Size*

Dependent variable: *Investment ratio*				
	Estimated coefficients (absolute t-ratios)			
	All firms	Science-based Non science-based Coefficient difference	Manager-controlled Owner-controlled Coefficient difference	Large Small Coefficient difference
Cash flow ratio	0.1116*** (5.59)	0.0932*** (3.43) 0.1441*** (4.53) –0.0508 (1.21)	0.0965*** (3.83) 0.1532*** (4.14) –0.0567 (1.27)	0.0950*** (4.40) 0.2656*** (4.52) –0.1706*** (2.72)
Sales-to-assets ratio	0.0376*** (7.98)	0.0369*** (5.75) 0.0393***(5.74) –0.0024 (0.25)	0.0305*** (5.45) 0.0585***(6.49) –0.0280*** (2.63)	0.0393*** (7.14) 0.0319***(3.86) 0.0074 (0.74)
Δ *Net working capital ratio*	–0.1237*** (5.01)	–0.0671* (1.92) –0.1936*** (5.77) 0.1264*** (2.61)	–0.1087*** (3.75) –0.1675*** (3.48) 0.0587 (1.04)	–0.1081*** (4.38) –0.2681*** (3.65) 0.1600** (2.07)
Δ *Long-term debt*	0.1608*** (7.27)	0.0868*** (2.76) 0.2589*** (8.66) –0.1720*** (3.96)	0.1387*** (4.64) 0.2046*** (7.06) –0.0658 (1.58)	0.1322*** (5.89) 0.4008*** (6.34) –0.2686*** (4.00)
Δ *Pension liabilities*	0.0433* (1.68)	0.0320 (0.92) 0.0493 (1.26) –0.0173 (0.33)	0.0560* (1.65) –0.0169 (0.40) 0.0731 (1.36)	0.0223 (0.84) 0.2247*** (3.07) –0.2023*** (2.60)
1993	–0.0099*** (2.91)	–0.0143*** (3.31) –0.0033 (0.60) –0.0110 (1.59)	–0.0112** (2.59) –0.0077 (1.43) –0.0035 (0.51)	–0.0090** (2.49) –0.0112 (1.45) 0.0022 (0.26)
1994	–0.0125*** (3.64)	–0.0179*** (4.14) –0.0032 (0.58) –0.0147** (2.10)	–0.0165*** (3.77) –0.0051 (0.95) –0.0114 (1.63)	–0.0133*** (3.62) –0.0103 (1.37) –0.0030 (0.36)
1995	–0.0128*** (3.79)	–0.0136*** (3.20) –0.0096* (1.78) –0.0040 (0.57)	–0.0139*** (3.20) –0.0106** (2.03) –0.0033 (0.48)	–0.0160*** (4.44) 0.0014 (0.18) –0.0174** (2.06)
1996	–0.0146*** (4.32)	–0.0151*** (3.56) –0.0136** (2.47) –0.0015 (0.22)	–0.0214*** (4.93) –0.0035 (0.66) –0.0179*** (2.61)	–0.0176*** (4.86) –0.0028 (0.37) –0.0148* (1.77)
Firms (pooled observations)	361 (1805)	223 (1115) 138 (690)	218 (1090) 143 (715)	295 (1475) 66 (330)

Notes:
Heteroskedasticity-consistent 2SLS-Within regression estimates from the balanced panel with 361 fixed firm-specific effects (coefficients not reported). The coefficient difference is the estimated coefficients for the science-based (manager-controlled, large) firms minus the coefficients for the non science-based (owner-controlled, small) firms. Instruments for Δ *Working capital ratio*: all other right-hand side variables plus the working capital ratio (t-1).

*, **, *** significant at the 0.10, 0.05, 0.01 level respectively

Table 5 Combining Knowledge Conditions, Corporate Governance and Firm Size

Dependent variable: *Investment ratio*								
	Estimated coefficient (abs. t-ratio)	Coefficient difference (absolute t-ratio)						
	(1) SML	(2) SOL	(3) SMS	(4) SOS	(5) NML	(6) NOL	(7) NMS	(8) NOS
Cash flow ratio	0.0773** (2.24)	–0.0183 (0.31)	0.1786* (1.92)	–0.0280 (0.16)	–0.0059 (0.12)	0.1660** (2.12)	0.2904** (1.98)	–0.0062 (0.05)
Sales-to-assets ratio	0.0232*** (2.81)	0.0419** (2.49)	0.0366** (2.00)	–0.0107 (0.41)	0.0125 (0.96)	0.0467*** (2.90)	–0.0131 (0.79)	0.0854*** (2.99)
Δ *Net working capital ratio*	–0.0489 (1.02)	–0.0317 (0.43)	–0.1491 (1.34)	0.0267 (0.43)	–0.0778 (1.34)	–0.3530*** (3.19)	–0.4355** (2.14)	–0.6043*** (4.95)
Δ *Long-term debt*	0.0605 (1.15)	0.0134 (0.22)	0.3093** (2.51)	0.0771 (0.53)	0.0732 (1.19)	0.5544*** (6.42)	0.5559*** (3.68)	0.5509*** (5.01)
Δ *Pension liabilities*	0.0367 (0.63)	–0.0593 (0.75)	0.1263 (0.96)	0.2181 (1.51)	–0.0268 (0.37)	0.0544 (0.49)	0.5497*** (2.94)	0.6798*** (3.41)
Firms (pooled observations)	111 (555)	74 (370)	21 (105)	17 (85)	73 (365)	37 (185)	13 (65)	15 (75)

Definitions:

(1) SML	large manager-controlled firms in science-based industries
(2) SOL	large owner-controlled firms in science-based industries
(3) SMS	small manager-controlled firms in science-based industries
(4) SOS	small owner-controlled firms in science-based industries
(5) NML	large manager-controlled firms in non science-based industries
(6) NOL	large owner-controlled firms in non science-based industries
(7) NMS	small manager-controlled firms in non science-based industries
(8) NOS	small owner-controlled firms in non science-based industries

Notes:

Heteroskedasticity-consistent 2SLS-Within regression estimates from the balanced panel with 361 fixed firm- and 4 time-specific effects (coefficients not reported). Adding the coefficient difference in columns (2) to (8) to the coefficient estimate in column (1) yields the coefficient for the respective group of firms. Instruments for Δ *Working capital ratio*: all other right-hand side variables plus the working capital ratio (t-1).

*, **, *** significant at the 0.10, 0.05, 0.01 level respectively (two-tailed test)

Table 6 *Estimated Cash Flow Elasticities and Firm Performance*

	(1) SML	(2) SOL	(3) SMS	(4) SOS	(5) NML	(6) NOL	(7) NMS	(8) NOS
Cash flow elasticity	0.11	0.09	0.47	0.11	0.12	0.32	0.69	0.12
Sales growth (in per cent)	1.11	3.50	0.70	8.86	0.84	4.52	–0.55	1.42
Return on total assets (in per cent)	27.03	31.31	33.53	26.63	29.44	29.60	28.28	34.49
Cost change (in per cent)	1.52	3.69	–0.36	8.74	0.69	4.70	–0.50	2.81
Employment change (in per cent)	–3.23	–0.42	–1.00	5.48	–3.67	–1.29	–4.43	–1.24

Definitions:

(1) SML large manager-controlled firms in science-based industries
(2) SOL large owner-controlled firms in science-based industries
(3) SMS small manager-controlled firms in science-based industries
(4) SOS small owner-controlled firms in science-based industries
(5) NML large manager-controlled firms in non science-based industries
(6) NOL large owner-controlled firms in non science-based industries
(7) NMS small manager-controlled firms in non science-based industries
(8) NOS small owner-controlled firms in non science-based industries

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Endnotes

[1] See in particular Jaffe and Russel (1976); Jensen and Meckling (1976); Stiglitz and Weiss (1981); Myers and Majluf (1984).

[2] Stiglitz and Weiss (1981) pointed out that, unlike in most other markets, the market for credit is exceptional in that the price of the good – the rate of interest – is not necessarily at a level that equilibrates the market. They attribute this to the fact that interest rates influence not only the demand for capital but also the risk inherent in different borrowers. As the rate of interest rises, so does the riskiness of borrowers, leading suppliers of capital to rationally decide to limit the quantity of loans they make at any particular interest rate. Most potential lenders have little information on the managerial capabilities or investment opportunities of firms and are unlikely to be able to screen out poor credit risks or to have control over a borrower's investments. If lenders are unable to identify the quality or risk associated with particular borrowers, Jaffe and Russell (1976) show that credit rationing will occur. This phenomenon is analogous to the lemons argument advanced by Akerlof (1970). The existence of asymmetric information prevents the suppliers of capital from engaging in price discrimination between riskier and less risky borrowers.

[3] See e.g. Chirinko (1993), Schiantarelli (1996), Hubbard (1998), or Weigand (1999) for surveys and discussion.

[4] See for evidence e.g. Fazzari et al. (1988); Fazzari and Petersen (1993); Bond and Meghir (1994); Gilchrist and Himmelberg (1995), Hubbard et al. (1995) on non-dividend paying firms; Gertler and Gilchrist (1994), Himmelberg and Petersen (1994), Petersen and Rajan (1994), Gilchrist and Himmelberg (1995) on small firms; Hubbard et al. (1995) on young firms; Binks and Ennew (1996) on growing small firms; Whited (1992) on leveraged firms; Hoshi et al. (1991), Binks and Ennew (1995, 1997), Ennew and Binks (1995) on non-bank affiliated firms; Whited (1992), Gilchrist and Himmelberg (1995) on firms without bond rating; Hall (1992), Hao and Jaffe (1993), Worthington (1995) on firms with R&D or high asset specificity; Gertler and Gilchrist (1994) on effects of business cycle downturns and tight monetary policy. Recent studies by Bond et al. (1997, 1999), Hall et al. (1999), and Mulkay et al. (1999) that compare firms from

the UK or the USA with Continental European firms in pooled panel data sets show a significantly stronger investment-cash flow relationship for the Anglo-American firms.

[5] See Short (1994) and Shleifer and Vishny (1997) for surveys and discussion.

[6] According to Shleifer and Vishny (1997, pp.755) there are several potential costs of having large investors: 'straightforward expropriation of other investors, managers, and employees; inefficient expropriation through pursuit of personal (non-profit-maximizing) objectives; and finally the incentive effects of expropriation on the other stakeholders.'

[7] Most studies have explored the impact of ownership structure on rates of return or capital structure. See Short (1994) for a recent survey.

[8] The sources used are Commerzbank's, *Wer gehört zu wem?*, Hypobank's *Wegweiser durch deutsche Aktiengesellschaften*, and Hoppenstedt's *Börsenführer*.

[9] The survey *Mannheimer Innovationspanel* conducted for the first time in 1992/93 by the Mannheim-based Zentrum für Europäische Wirtschaftsforschung (ZEW) contains data on innovation and investment collected from more than 43,000 West German manufacturing firms.

[10] See Baums (1994, pp. 425) for a discussion of the German dual boards system.

[11] Replacement values of assets were not available and could not be calculated either, since the investment series is too short.

[12] See Chirinko (1993) and Hubbard (1998) who discuss measurement issues in more detail.

[13] Usually, data have to be first-differenced to get rid of fixed effects. The first-differenced right-hand side variables are then instrumented by their respective levels lagged at least two periods. While taking care of contemporaneous simultaneity and measurement error, the dynamic panel data estimators tend to have large standard errors due to the fact of weak instruments (see Blundell and Bond, 1995). See Baltagi (1995) on estimators for static and dynamic panel data models.

[14] See Fazzari and Hubbard (1993) for a detailed discussion of instrumenting the change in working capital.

[15] See Edwards and Fischer (1994), Baums (1994), or Roe (1994) for a more comprehensive discussion.

[16] Studies using aggregate data show that bank loans are by far the most important source of external firm finance in Germany (Edwards and Fischer, 1994; C. Weigand, 1998).

[17] Estimating model (3) yields exactly the same regression coefficients as those that would result from estimating model (1) separately for the subgroup of science-based firms and the subgroup of non science-based firms. However, given that the variance of the regression errors is constant over the sample period, a coefficient estimate from model (3), since based on *all* available observations, is efficient, whereas the estimates obtained from the two separate subgroups are not.

[18] The t-test assumes that variances are unequal across the subsets. Degrees of freedom are given in brackets behind the t-statistic.

[19] Alternatively, we used the change in real sales as sole or additional proxy for investment opportunities. The coefficients were insignificantly positive when the sales-to-assets ratio was dropped from the equation, and insignificantly negative when included.