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

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Abstract

This paper examines the impact of industry knowledge conditions, firm size 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 information and non-exclusiveness of newly created knowledge 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. However, firm size and governance structures play an important role. After accounting for firm size and the mode of corporate governance, we observe that the large owner-controlled firms in both science- and non science-based industries are most liquidity constrained.

Keywords: Determinants of investment, liquidity constraints, corporate governance

JEL classification: G3, L2, O31

1. Introduction

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 (see, e.g., Stiglitz and Weiss, 1981). Due to capital market imperfections firms may face financing constraints for investment rather than having unlimited access to external finance as the neoclassical model of the firm assumes. A second wave of empirical studies established in fact considerable evidence suggesting that financing constraints do exist, and that they are shaped by characteristics specific to the firm. However, most of these studies do not look at the role that the industry environment plays in liquidity constraints. This oversight may be crucial if it is the knowledge conditions underlying different industries that may result in liquidity constraints in the first place. As Kenneth Arrow (1962) pointed out in his seminal article, the knowledge conditions underlying an industry vary systematically across industries. In some industries innovation depends more on basic scientific knowledge and systematic R&D than in others. 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 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, while controlling firm size and the mode of governance. Science-based industries generally fit the characteristics of market failure identified by

Arrow (1962) in that they are based on economic activity, which is characterized by uncertainty, asymmetric information and non-exclusiveness of newly created knowledge. Based on a panel data set of German firms we find evidence suggesting that science does make a difference. However, the way in which it does make a difference is surprising.

2. Why Should Science Make A Difference?

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). As Fazzari, Hubbard and Petersen (1988, p. 141) point out, "Empirical models of business investment rely generally on the assumption of a 'representative firm' that responds to prices set in centralized security markets. Indeed, if all firms have equal access to capital markets, firms' responses to changes in the cost of capital or tax-based investment incentives differ only because of differences in investment demand." According to this view, the financial structure of a firm does not play an important role in investment decisions, since the firm can costlessly substitute external funds for internal capital. Under the assumption of perfect capital markets, firm-specific investment decisions are generally independent of the financial condition of the firm.

The assumption of perfect capital markets has, of course, been rigorously challenged. Once capital markets are no longer assumed to be perfect, external finance can also no longer be assumed to be a perfect substitute for internal capital. An implication of this view is that the availability of internal finance, access to new debt or equity finance, and other financial factors may shape firm investment decisions. 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 such 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.

Scholars responded to the theories predicting liquidity to be constrained with a wave of empirical studies.[1] Almost all of the empirical work has followed the seminal article by Fazzari et al. (1988) and inferred the existence of liquidity constraints on the basis of an investment-cash flow regression.[2] A regression coefficient of the firm's cash flow that is equal to zero is interpreted as reflecting a perfect capital market and therefore no liquidity constraints, since external capital is a perfect substitute for internal capital. By contrast, 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.

The most recent firm-level studies test for the presence and impact of financing constraints on the basis of *a priori* firm-specific factors. These studies have followed the lead of Fazzari et al. (1988), who linked firm-specific characteristics, namely dividend payout and firm size, to the impact of cash flow on investment. Subsequent studies have elaborated on the cash flow-investment link by investigating further firm-specific variables. In particular, finance constraints have been found to exist for non-dividend paying firms (Fazzari et al., 1988; Fazzari and Petersen, 1993; Bond and Meghir, 1994; Gilchrist and Himmelberg, 1995; Hubbard et al., 1995), small firms (Gertler and Gilchrist, 1994; Himmelberg and Petersen, 1994; Petersen and Rajan, 1994; Gilchrist and Himmelberg, 1995), young firms (non-mature firms) (Hubbard et al., 1995), growing firms (Binks and Ennew, 1996), leveraged firms (Whited, 1992), non-bank affiliated firms (Hoshi et al., 1991; Binks and Ennew, 1995 and 1997; Ennew and Binks, 1995), firms without bond rating (Whited, 1992 and Gilchrist and Himmelberg, 1995), and firms with high-asset specificity (Worthington, 1995). This growing literature provides compelling empirical evidence that (1) external finance is constrained under certain conditions and (2) liquidity constraints vary systematically with firm-specific characteristics.

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 inherent in innovative activity that are not present in other goods. 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 is economic knowledge.

The third source of market failure stems from the public good nature and non-exclusive externalities inherent in science-based economic activity. The production of knowledge does not preclude other economic agents from applying that knowledge for economic gain. It is difficult to delineate and enforce property rights to newly created knowledge. 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 *non-exclusivity* 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. Cash flow, 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). 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.

A second important direction of the literature has been devoted towards identifying the impact that corporate governance has on the extent of financing constraints. Since they reduce the transaction cost and agency costs associated with knowledge asymmetries, different modes of corporate governance have been predicted to alleviate liquidity constraints (see, e.g., Jensen and Meckling, 1976). In the governance literature it has been argued that block holding (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 that fosters the availability of external finance.[3] For example, Elston and Albach (1995) and Bond et al. (1997) hypothesize that having banks as (co-)owners of industrial firms is a governance mechanism in Germany that alleviates liquidity constraints. They compare the impact of cash flow on investment between bank-owned and non bank-owned firms and find that the non-bank affiliated firms tend to experience greater liquidity constraints. Similarly, having a large corporation as main shareholder may provide backup finance and collateral for the owned firm's investment. The empirical evidence reported by Lang and Stulz (1994) as well as Shin and Stulz (1998), however, implies that diversified large US firms did not channel internal funds efficiently into those segments with the best investment opportunities. Therefore, subsidiaries may be liquidity constrained as well. Haid and Weigand (1998), by contrast, find that German firms majority-held by other industrial firms did not suffer from liquidity constraints for R&D and tangible investments, whereas family-owned German firms were significantly constrained by the availability of internal and external funds. If the mode of governance affects the extent of knowledge asymmetries and thus the access to external finance we would expect the impact of corporate governance to be more pronounced in science-based industries.

3. Measurement

The data

To estimate if the liquidity constraints of science-based firms differ from non science-based firms, we apply a data set of 342 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*); 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 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.[4] Annual observations were available for each firm between 1991 and 1996, making it possible to construct a panel data set. 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).[5] 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 as well as the highest share of firms with R&D budgets and in-house R&D laboratories. Further, economic activities in these industries are typically 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 215 firms into science-based and 127 into non science-based industries.

[Table 1 about here]

Regression models and hypotheses

We estimate the regression model:

(1)

$$\frac{I_{it}}{A_{it-1}} = b_1 \frac{CF_{it}}{A_{it-1}} + b_2 \frac{S_{it}}{A_{it-1}} + b_3 \frac{\Delta_t WC_i}{A_{it-1}} + b_4 \frac{B_{it}}{A_{it-1}} + b_5 OWNCONC_{it} + b_6 SIZE_{it} + b_7 H_{ijt} + m_{it}$$

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 scale factor.[6] *CF* denotes cash flow (operating income plus depreciation charges plus the year-to-year change in liability reserves), *S* current sales, Δ *WC* the year-to-year change in working capital (current assets minus current liabilities), and *B* bank loans. *OWNCONC* is the cumulated share of the three largest shareholders in a firm’s outstanding capital, with large meaning a share of five percent and more of the voting capital.[7] *SIZE* is absolute firm size, measured by the log of total employment. As an indicator of the degree of supplier concentration we use the Herfindahl index, *H*, at the two-digit industry level (SYPRO industry classification). The subscript *j* denotes the two-digit industry in which the respective firm *i* is classified.

The impact of cash flow on investment is reflected by the coefficient b_1. If capital markets are imperfect and investment opportunities are properly controlled for, we would expect that $b_1 > 0$. 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 (165) 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 assets and thus the need for additional investment (see Brealey and Myers, 1984, p. 574). We would expect $b_2 > 0$. An important qualification is that these proxy measures may introduce measurement bias. Studies have typically 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.[8] 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. A solution to this problem was suggested by Fazzari and Petersen (1993). They point out that a firm confronted by liquidity constraints typically adjusts 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 working capital to separate the profitability indicating part of cash flow from its liquidity role. Therefore, if a firm is finance constrained, we would expect an inverse relationship between investment and the change in working capital, $b_3 < 0$. Since the change in working capital tends to be positively correlated with profits or sales, we should also observe a positive coefficient for the change in working capital in the investment equation, $b_3 > 0$, if cash flow signals investment opportunities rather than liquidity. However, investment in working capital is an endogenous variable just like tangible investment. To account for this simultaneity we use two-stage least square estimation techniques and instrument the change in working capital by the lagged working capital ratio plus all other right-hand side variables from regression equation (1).[9]

There are two possible sources to finance investment – internally generated funds and external finance. Under perfect capital markets investment and financing decisions are independent so the choice of financing instruments such as retained earnings, issuance of new equity, bonds, or bank borrowing does not matter (except for tax purposes). Changes in capital structure should not affect investment spending. However, if investment is not separable from finance because capital markets are imperfect, agency costs arise that render not only internal and external finance but also alternative instruments of external finance imperfect substitutes. In Germany, bank loans are by far the most important source of external firm finance (Edwards and Fischer, 1994; C. Weigand, 1998). 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 participations, proxy voting rights, board representation).[10] To test the importance of bank loans for investment spending we include the bank loan ratio as an additional regressor in the estimating equation and expect bank borrowing to be positively related to investment, $b_4 > 0$, if firms are financially constrained.

We use the degree of ownership concentration and the identity of owners as indicators of the potential range of corporate governance, or the tightness of control over the firm exercised by the actual owners. If large shareholders are better able to exercise control and thus reduce agency conflicts with managers as well as with external capital providers ownership concentration might have a positive impact on investment.[11] In diffusely held companies hired managers may be able to use free cash flow for pet projects, perks etc. rather than productive investment.[12] Therefore, we distinguish between manager-controlled and owner-controlled firms. We define a firm as owner-controlled if individuals or families have equity stakes of over 25% and there is no other identifiable larger shareholder (such as another independent company, bank, or insurance company). All other firms, with another company, banks or insurance companies as largest shareholders, are defined as manager-controlled, since we assume that it is hired managers rather than the ultimate owners who exercise control. Here we may expect interest conflicts arising from the separation of ownership and control that affect investment decisions.

A large literature dating back to Schumpeter (1942) argues that firm R&D is positively related to firm size and the degree of market concentration. This is because of the increased ability of firms with market power to appropriate the returns accruing from their investments in new knowledge. Therefore, we would also expect firm size and market concentration to have a positive impact on tangible investment. By contrast, market power and large size may cause managerial and organizational slack. Funds may be misused for pet projects rather than invested in productive assets. We thus might find an inverse relationship between firm size or concentration and investment.

In sum, for firms operating under a regime of financial constraints we should observe $b_1 > 0$, $b_2 > 0$, $b_3 < 0$ and $b_4 > 0$ to be statistically significant. If ownership concentration affects investment decisions directly b_5 should be significantly different from zero. The impact of firm size and market concentration is indeterminate a priori.

If knowledge conditions or the mode of governance (the identity of owners, control by hired managers) make a difference for the presence of liquidity constraints or the impact of any other variable we would expect to observe differences in coefficients between subgroups of firms. To test for differences in the slope coefficients across 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

$$(2) \qquad \frac{I_{it}}{A_{it-1}} = b_1 \frac{CF_{it}}{A_{it-1}} + d_1 D_i \times \frac{CF_{it}}{A_{it-1}} + b_2 \frac{S_{it}}{A_{it-1}} + d_2 D_i \times \frac{S_{it}}{A_{it-1}} + \mathrm{K} + m_{it} \,.$$

For example, to compare coefficients between science-based and non science-based firms we define D_i as

$$\begin{aligned} D_i &= 1 \quad \text{if firm } i \text{ is in a science-based industry,} \\ &= 0 \quad \text{otherwise.} \end{aligned}$$

The b coefficients then measure the impact of the respective variables on investment of the non science-based firms, whereas the d coefficients measure the difference between the bs and the slope coefficients of the science-based firms. Adding ds to bs, or estimating the equation with the dummy variable defined the other way around, yields the slope coefficients for the science-based firms.[13]

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 terms m_{it} in models (1) and (2) to be represented by

$$(3) \qquad m_{it} = a_i + l_t + n_{it} ,$$

where a_i are fixed (time-invariant) firm-specific parameters, l_t refer to time-specific (firm-invariant) effects and $n_{it} \sim \text{iid}\left(0, s_n^2\right)$ denote white noise disturbances. Given this formulation of the error term we estimate regression equations (1) and (2) using a Within-2SLS estimator.[14]

4. Results

Descriptive statistics

Table 2 compares the means and medians of selected variables between science-based and non science-based firms, as well as between large and small firms. We define small firms as having fewer than 500 employees.[15]

[Table 2 about here]

Table 2 indicates that investment ratios tend to be smaller in the science-based industries than in the non science-based industries for both large and small firms. This presumably reflects a greater reliance on intangible assets than on tangible assets in the science-based firms. Unfortunately, we cannot investigate R&D investment directly because annual firm-specific R&D expenses were not available for most of the firms included in this data set.[16] The cash flow and sales-to-assets ratios are higher for the non science-based firms. Regarding sales and employment, large firms in the science-based industries tend to be larger than their counterparts in the non science-based industries. The annual rate of change in employment was negative in both science and non-science based industries. However, employment downsizing was less severe in the science-based industries. The science-based firms also experienced higher rates of sales growth. The bank loans ratio was lower for firms from science-based industries. This may indicate that investment projects in science-based industries are preferably financed internally because of higher uncertainty. It may also reflect a greater reliance on secrecy if external finance requires the revelation of project details so that sensitive information might leak out and spill over to competitors. The share of working capital, which can be used to smooth investment when cash flow shocks occur, is greater for science-based firms. There is no obvious difference regarding ownership concentration but half of the firms in each subgroup have maximum ownership concentration anyway. Supplier concentration is slightly higher in non science-based industries but the Herfindahl indices are rather low.

Table 3 refines the previous table by considering the mode of governance. The manager-controlled firms tend to be larger, invest less in tangible assets, have lower sales growth, a more negative employment development, lower cash flow ratios, a clearly lower bank loan ratio, and a lower working capital ratio than the owner-controlled firms.[17]

[Table 3 about here]

Regression results

The regression results from estimating model (1) for the full sample of firms and from model (2) considering differences in knowledge conditions 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. As expected if liquidity constraints are present, coefficients of cash flow and bank borrowing are positive and statistically significant, whereas the change in working capital is significantly negative and the sales-to-assets ratio, controlling for investment opportunities, is significantly positive.[18]. Calculated at median values (taken from Table 1), the elasticity of investment with respect to cash flow is 0.27. 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).

Differences in knowledge conditions matter. There is a statistically significant difference in the extent of liquidity constraints between science-based and non science-based firms, as the last column in Table 4 documents. Contrary to what one would expect, liquidity constraints are *less* severe in science-based industries. After accounting for knowledge conditions, we find cash flow elasticities of 0.20 for the science-based firms and of 0.40 for the non science-based firms. The non science-based firms also smoothed investment significantly more by adjusting working capital. Regarding external finance, investment of both science-based and non-science based firms is significantly positively affected by the availability of bank loans. However, the availability of bank loans is significantly more important for the non science-based firms. The estimated coefficients suggest that, at median values, a 10 per cent increase in the bank loan ratio equals a 1.4 per cent increase in the investment ratio for science-based firms and a 5.9 per cent increase for non science-based firms. At the same time, firm size has a significantly positive impact on investment for the science-based but not for the non science-based firms. Taken together, this supports the Schumpeterian view that firm size reduces uncertainty, generates internal funds for financing investment and makes external finance, especially from banks, less important. Supplier concentration does not favor tangible investment, the non science-based firms are even significantly negatively affected (median elasticity 0.45).

For the non science-based firms ownership concentration seems to provide governance that is favorable for investment. Since median ownership concentration is 100 percent in both subgroups and most of the “other half” firms are majority-held, the results imply a significant difference between majority and dominant ownership for this subgroup of firms. The estimated coefficient yields an elasticity of 1.24 at median values, which is clearly larger than the calculated cash flow elasticities. Thus an increase of ownership concentration from majority control (50 per cent) to total control (100 per cent) more than doubles the investment ratio.

Firm size has been identified in the literature as an important characteristic that can be linked to liquidity constraints. In particular, Fazzari et al. (1988) and others found that the degree of liquidity constraints tends to be negatively related to firm size. To examine the impact of firm size on the extent of liquidity constraints, we divide the data set into the sub-samples of large and small firms. The regression results are contained in Tables 5 and 6.

[Table 5 about here]

In Table 5 industry knowledge conditions are ignored.[19] 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 median values is 0.71, which is very close to what Himmelberg and Petersen (1994) found for small R&D intensive US firms. The availability of bank finance is clearly more important for the small firms. The split of the sample according to firm size classes renders the coefficients on ownership concentration and supplier concentration insignificant but there is still a significantly positive, direct impact of firm size for the subgroup of large firms.

Table 6 considers both firm size and knowledge conditions and presents estimated coefficients for the large science-based, the large non science-based and the small science-based firms as well as coefficient differences between any two subgroups.[20] It is evident that the large science-based firms are significantly less constrained than any other subgroup. They have the smallest coefficients on cash flow, working capital and bank loans. The coefficient of the change in working capital is even insignificant. This is also true for the small science-based firms that appear to be less constrained than both large and small firms from non science-based industries. The differences in slope coefficients concerning liquidity constraints are statistically significant at least between the two subgroups of small firms. Striking is the finding that, while firm size and supplier concentration have a significantly positive impact on investment for the small science-based firms, the coefficients actually become negative and statistically significant for the non science-based firms. However, these results are tentative and have to be interpreted with caution, since the subgroup of small firms in our sample is rather small. As Table 6 shows, the positive impact of ownership concentration and the negative impact of supplier concentration observed for the non science-based firms in Table 4 emanate from the large firms.

Finally, to examine how the mode of corporate control affects the extent of liquidity constraints, we consider manager-controlled versus owner-controlled firms. The results are presented in Tables 7 and 8.

Table 7 examines science-based firms. The manager-controlled large firms are significantly less constrained than either the owner-controlled large firms or the manager-controlled small firms. The coefficient of the change in working capital is insignificant for the manager-controlled large firms but highly significant and larger for both the owner-controlled large firms and the manager-controlled small firms. For the owner-controlled small firms, the coefficient of the change in working capital is surprisingly insignificantly positive, while the impact of cash flow on investment is larger than for the other subgroups. Again caution in interpretation is warranted because of the small size of the subsample but cash flow might reflect future profitability and investment opportunities of these owner-controlled small firms rather than liquidity constraints. As we 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. However, changes in investment spending are significantly affected by the availability of bank loans. Small firms have to rely on banks' support to exploit the presumably richer investment opportunities in science-based industries. Differences in firm size and supplier concentration tend to have opposite impacts on small firm investment depending on the mode of governance. Investment of the small manager-controlled firms benefits from larger size and more concentrated market structures, whereas a negative impact is observed for the owner-controlled small firms.

Table 8 summarizes the evidence of the impact of corporate governance on the extent of liquidity constraints for non science-based firms. Clearly, the *owner-controlled large* firms are more constrained than the other subgroups of firms. They have significantly larger coefficients on both cash flow and change in working capital than the large and small manager-controlled as well as the small owner-controlled firms. The cash flow elasticity of investment is 0.76 for the non science-based large and owner-controlled firms compared to 0.32 for their science-based counterparts. The positive impact of ownership concentration and the negative impact of supplier concentration reported in Tables 4 and 6 for the non science-based, large firms can now be traced back to the owner-controlled firms.

5. 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. In particular, we compared the extent of liquidity constraints between 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, we find that two firm characteristics, firm size and the mode of governance, 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 makes a difference in that the small science-based firms are *less* constrained than either the large or small non science-based firms. Considering governance structures, we observe that is a governance mechanism favorable for tangible investment in non science-based, large owner-controlled firms. However, we identified the subset of large owner-controlled firms in both science-based and non science-based industries as financially most constrained, with the non science-based firms being significantly more constrained. For the large manager-controlled firms but also for the small owner-controlled firms operating in science-based industries our results imply modest liquidity constraints at best.

At first glance, it is puzzling that among the owner-controlled firms the large firms and not the small ones are more liquidity constrained. However, it should be emphasized that the dual role of cash flow – indicating future profitability and prospects of success as well as current liquidity – may be most relevant for science-based firms. The ability to generate cash flow provides not just a source of finance but also signals market success and viability under conditions of hyper-uncertainty, hyper-knowledge asymmetries, and potential non-exclusivity. For an owner-controlled small firm, survival under such "hyper-…" conditions may amplify the cash flow signal to capital providers external to the firm and alleviate the access to external finance. Despite a larger potential for knowledge asymmetries knowledge-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). Financing growth internally and through banks may be efficient only up to a certain firm size. Here the mode of governance comes into play. The financial constraints of the *large owner-controlled* firms may reflect growth thresholds that cannot be crossed given the current potential to generate internal funds and attract bank loans. The respective firms in our sample tend to have higher investment ratios, sales growth, cash flow ratios, and bank loan ratios but also higher sales-to-assets ratios, indicating the need for still more investment. If the possibilities of internal finance and bank finance are exploited successful firms could attract new equity by going public. Aside from the costs involved and the requirements that have to be fulfilled with going public, this would mean for the firm's owners to trade control over the firm off for new equity.[21] Firm owners, who are often also the founders of the respective firms, may not be willing to resign from total control and rather prefer slower growth by accepting financing constraints.

From our viewpoint, the findings in this study have two major implications. First, the link between investment and finance is 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 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.

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Table 1 Industries, R&D characteristics, and distribution of sample firms

Industry	R&D intensity*	Firms with R&D**	Firms with a R&D division**	Firms with innovations**	Classified as science-based	Firms in the data set
Chemicals and allied products	8.1	57	32	78	Yes	58
Machinery, except electrical	3.3	44	18	79	Yes	73
Motor vehicles and allied products	5.3	40	19	56	Yes	18
Electric and electronic equipment	6.0	63	47	78	Yes	54
Instruments and related products	5.1	41	17	57	Yes	10
Aircraft and aerospace technologies	n.a.	n.a.	n.a.	n.a.	Yes	2
Rubber and plastic products	1.6	45	27	65	No	4
Stone, clay and glass products	0.8	17	2	48	No	29
Primary metal industries	1.1	30	13	52	No	36
Steel and light metal construction	2.9	9	6	40	No	4
Fabricated metal products	0.9	37	13	71	No	15
Lumber and allied products, paper and allied products, printing	0.9	12	2	45	No	4
Leather and leather products, textile mill products, apparel and other textile products	1.9	25	10	46	No	5
Food and kindred products, tobacco manufacturers	0.6	7	4	24	No	4
Other manufacturing	n.a.	n.a.	n.a.	n.a.	No	26

* 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 fuer Europaeische Wirtschaftsforschung), including 43,300 West German firms.
** in per cent of all reporting firms, source: Beise and Licht (1996).

Table 2 *Summary statistics, 1991-1996*

Variables	Mean Median								
	Full sample			Science-based firms			Non science-based firms		
	All firms	Large	Small	All firms	Large	Small	All firms	Large	Small
Investment expenditures (t) / total assets (t-1) (in per cent)	7.33 5.89	7.32 6.16	7.41 4.50	6.43 5.34	6.48 5.60	6.12 3.98	8.86 6.91	8.78 7.06	9.31 5.34
Sales (t) / total assets (t-1) (in per cent)	155.9 142.0	151.9 140.4	178.2 154.5	154.0 139.0	148.3 138.6	187.7 152.0	159.1 146.3	158.1 144.2	164.2 155.7
Sales (in millions DM)	3,525 670	4,129 985	153 62	3,996 781	4,645 1,094	142 63	2,728 557	3,235 803	169 57
Sales growth (in per cent)	2.07 2.28	2.07 2.51	2.07 1.63	2.52 2.76	2.26 3.00	4.08 1.63	1.31 1.41	1.74 1.29	–0.86 1.59
Employment	11,405 2,391	13,402 3,385	270 278	13,384 2,499	15,595 3,840	256 253	8,056 2,170	9,594 2,913	291 316
Employment growth (in per cent)	–2.46 –2.49	–2.78 –2.60	–0.69 –1.61	–1.71 –2.32	–2.17 –2.42	1.04 –1.26	–3.73 –2.87	–3.83 –2.92	–3.25 –2.38
Ownership concentration (C3) (in per cent)	85.00 100.0	83.09 100.0	91.02 100.0	84.90 100.0	84.05 100.0	89.94 100.0	85.18 100.0	83.71 100.0	92.60 100.0
Cash flow (t) / total assets (t-1) (in per cent)	11.09 10.85	10.90 10.85	12.10 10.93	10.24 10.38	10.06 10.58	11.27 9.73	12.52 11.44	12.36 11.39	13.33 11.85
Bank loans (t) / total assets (t-1) (in per cent)	17.06 12.21	16.27 11.50	21.48 15.76	15.92 10.59	15.30 10.07	19.64 13.52	19.00 15.29	17.97 14.69	24.20 19.00
Working capital (t) / total assets (t-1) (in per cent)	33.19 32.79	33.03 32.63	34.09 34.23	35.84 35.91	35.78 35.67	36.14 37.32	28.71 27.31	28.24 27.28	31.05 28.00
(Working capital (t) – Working capital (t-1)) / total assets (t-1) (in per cent)	1.78 0.90	1.91 0.98	1.06 0.27	2.10 1.01	2.18 1.04	1.66 0.75	1.24 0.65	1.45 0.81	0.17 0.24
Supplier concentration (Herfindahl index, range [0; 10,000])	552 306	576 306	413 299	476 298	507 298	294 298	679 473	697 478	588 339
Number of firms	342	290	52	215	184	31	127	106	21
thereof: quoted	177	153	24	110	96	14	67	57	10

Notes: t end-of-the-year values, (t-1) beginning-of-the-year values.

Table 3 *Summary statistics: Manager-controlled firms vs. owner-controlled firms, 1991-1996*

Variables	Mean Median							
	Science-based firms				Non science-based firms			
	Manager-controlled		Owner-controlled		Manager-controlled		Owner-controlled	
	Large	Small	Large	Small	Large	Small	Large	Small
Investment expenditures / total assets (in per cent)	6.12 5.10	6.01 3.96	7.22 6.64	6.27 4.33	7.50 6.65	9.29 6.35	12.17 9.55	9.32 4.91
Sales (t) / total assets (t-1) (in per cent)	146.1 134.2	184.3 141.2	152.8 144.2	192.5 155.5	152.1 140.0	157.0 129.9	174.1 157.1	168.6 172.0
Sales (in millions DM)	5,138 1,145	174 64	3,626 863	98 60	4,157 1,281	306 53	786 481	85 59
Sales growth (in per cent)	1.52 2.07	2.21 –0.07	3.79 4.40	6.67 2.01	1.42 1.19	–5.41 –4.80	2.60 2.80	1.94 2.80
Employment	15,536 4,275	265 253	15,718 2,998	244 248	11,804 3,366	262 256	3,726 2,367	308 322
Employment growth (in per cent)	–3.12 –3.28	–0.93 –1.93	–0.21 –0.78	3.77 –0.12	–4.36 –3.58	–5.14 –2.47	–2.40 –0.58	–2.08 –1.94
Ownership concentration (C3) (in per cent)	82.18 100.0	85.81 100.0	87.91 100.0	95.66 100.0	83.07 97.20	97.33 100.0	85.42 100.0	89.69 100.0
Cash flow (t) / total assets (t-1) (in per cent)	8.95 9.70	11.82 8.73	12.36 12.00	10.52 11.10	11.14 10.33	12.33 11.37	15.59 14.10	13.94 13.06
Bank loans (t) / total assets (t-1) (in per cent)	12.07 6.87	17.98 12.16	21.97 16.32	21.94 16.61	14.99 10.69	15.56 8.47	25.90 23.36	29.51 29.26
Working capital (t) / total assets (t-1) (in per cent)	35.76 34.74	35.05 35.20	35.84 37.25	37.66 38.85	28.69 27.58	31.37 24.04	27.04 25.36	30.86 31.17
(Working capital (t) – Working capital (t-1)) / total assets (t-1) (in per cent)	2.15 1.01	2.51 2.12	2.24 1.20	0.47 –0.62	1.48 0.80	1.22 0.24	1.38 0.84	–0.47 0.44
Supplier concentration (Herfindahl index, range [0; 10,000])	565 298	360 417	387 264	202 268	750 482	851 572	557 244	427 180
Number of Firms	124	18	60	13	77	8	29	13
thereof: quoted	60	9	36	5	38	4	19	6

Notes: t end-of-the-year values, (t-1) beginning-of-the-year values.

Table 4 *Investment, Finance, and Corporate Governance: Science-based versus Non Science-based Firms*

Dependent variable: *Investment ratio*				
	Estimated Coefficients			Coefficient difference
	All firms	Science-based firms	Non science-based firms	Science vs. non science
Cash flow ratio	0.1461*** (6.10)	0.1029*** (3.49)	0.2424*** (6.14)	0.1394*** (2.83)
Sales-to-assets ratio	0.0412*** (6.81)	0.0375*** (4.48)	0.0383*** (4.47)	0.0008 (0.06)
Δ *Working capital ratio*	–0.0728** (2.31)	–0.0389* (1.85)	–0.1390*** (5.12)	–0.1001*** (2.92)
Bank loan ratio	0.1365*** (8.29)	0.0743*** (3.63)	0.2669*** (9.41)	0.1925*** (5.51)
Ownership concentration	0.0373 (1.57)	0.0203 (0.71)	0.0859** (2.10)	0.0656 (1.32)
Firm size	0.0180** (2.46)	0.0257** (2.52)	0.0146 (1.41)	–0.0111 (0.77)
Market concentration	–0.0997 (0.91)	–0.0190 (0.17)	–0.6513** (2.09)	–0.6323* (1.91)
Number of firms Observations (pooled)	342 1368	215 860	127 508	

Notes:

Heteroskedasticity-consistent 2SLS-Within regression estimates; absolute t-ratios in parentheses. Balanced panel with 342 fixed firm-specific and 3 fixed time-specific effects (coefficients not reported).

Adding / subtracting the coefficient difference to / from the estimated coefficients for the science-based firms / non science-based firms yields the coefficients for the non science-based firms / science-based firms.

Instruments for Δ *Working Capital* : all other right-hand side variables, working capital ratio (t–1).

* significant at the 10% level (two-tailed test)

** significant at the 5% level (two-tailed test)

*** significant at the 1% level (two-tailed test)

Table 5 *Firm Size and Liquidity Constraints*

Dependent variable: *Investment ratio*				
	Estimated Coefficients			Coefficient difference
	All firms	Large firms	Small firms	Large vs. small
Cash flow ratio	0.1461*** (6.10)	0.1320*** (5.18)	0.2912*** (4.55)	0.1592** (2.30)
Sales-to-assets ratio	0.0412*** (6.81)	0.0365*** (5.17)	0.0458*** (4.04)	0.0093 (0.69)
Δ *Working capital ratio*	–0.0728** (2.31)	–0.0548*** (3.01)	–0.1629*** (3.73)	–0.1080** (2.28)
Bank loan ratio	0.1365*** (8.29)	0.1043*** (5.88)	0.2978*** (7.42)	0.1936*** (4.41)
Ownership concentration	0.0373 (1.57)	0.0316 (1.29)	0.0666 (0.86)	0.0349 (0.43)
Firm size	0.0180** (2.46)	0.0158* (1.94)	0.0194 (1.19)	0.0036 (0.20)
Market concentration	–0.0997 (0.91)	–0.0905 (0.84)	0.0569 (0.09)	0.1474 (0.22)
Number of firms Observations (pooled)	342 1368	290 1160	52 208	

Notes:
Heteroskedasticity-consistent 2SLS-Within regression estimates; absolute t-ratios in parentheses. Balanced panel with 342 fixed firm-specific and 3 fixed time-specific effects (coefficients not reported).

Instruments for Δ *Working Capital* : all other right-hand side variables, working capital ratio (t–1).

* significant at the 10% level (two-tailed test)

** significant at the 5% level (two-tailed test)

*** significant at the 1% level (two-tailed test)

Table 6 *Firm Size and Knowledge Conditions as Determinants of Liquidity Constraints*

Dependent variable: *Investment ratio*									
	Estimated coefficients	Coefficient difference			Estimated coefficients	Coefficient difference		Estimated coefficients	Coefficient difference
	Large science-based firms	Large non science-based firms	Small science-based firms	Small non science-based firms	Large non science-based firms	Small science-based firms	Small non science-based firms	Small science-based firms	Small non science-based firms
Cash flow ratio	0.0855*** (2.70)	0.1500*** (2.87)	0.0850 (0.97)	0.2438** (2.16)	0.2355*** (5.67)	–0.0650 (0.71)	0.0938 (0.81)	0.1705** (2.09)	0.1588* (1.71)
Sales-to-assets ratio	0.0322*** (3.32)	–0.0006 (0.04)	0.0119 (0.64)	0.0288 (1.53)	0.0316*** (3.12)	0.0125 (0.66)	0.0294 (1.54)	0.0441*** (2.78)	0.0169 (0.75)
Δ *Working capital ratio*	–0.0302 (1.32)	–0.0743** (2.03)	–0.0035 (0.06)	–0.2770*** (3.69)	–0.1045*** (3.66)	0.0708 (1.13)	–0.2026*** (2.63)	–0.0336 (0.60)	–0.2735*** (3.02)
Bank loan ratio	0.0430* (1.95)	0.1855*** (4.95)	0.1904*** (3.69)	0.4057*** (5.27)	0.2285*** (7.55)	0.0049 (0.09)	0.2201*** (2.76)	0.2334*** (5.01)	0.2152** (2.47)
Ownership concentration	0.0109 (0.37)	0.0669 (1.35)	0.1105 (1.32)	0.1513 (0.43)	0.0778** (1.96)	0.0435 (0.50)	0.0844 (0.24)	0.1213 (1.55)	0.0409 (0.11)
Firm size	0.0135 (1.07)	0.0073 (0.45)	0.0249 (1.19)	–0.1107* (1.78)	0.0207** (2.03)	0.0177 (0.90)	–0.1179* (1.91)	0.0384** (2.29)	–0.1356** (2.15)
Market concentration	–0.0167 (0.15)	–0.6221* (1.79)	2.5322** (1.98)	–0.2766 (0.33)	–0.6388* (1.94)	3.1543** (2.40)	0.3455 (0.39)	2.5155** (1.97)	–2.8088* (1.85)
Number of firms Observations (pooled)	184 736	106 424	31 124	21 84	106 424	31 124	21 84	31 124	21 84

Notes:

Heteroskedasticity-consistent 2SLS-Within regression estimates; absolute t-ratios in parentheses. Balanced panel with 342 fixed firm-specific and 3 fixed time-specific effects (coefficients not reported).

Instruments for Δ *Working Capital* : all other right-hand side variables, working capital ratio (t–1).

* significant at the 10% level (two-tailed test)

** significant at the 5% level (two-tailed test)

*** significant at the 1% level (two-tailed test)

Table 7 *Science-based Industries: Manager-controlled vs. Owner-controlled Firms*

Dependent variable: *Investment ratio*									
	Estimated coefficients	Coefficient difference			Estimated coefficients	Coefficient difference		Estimated coefficients	Coefficient difference
	Large manager-controlled firms	Large owner-controlled firms	Small manager-controlled firms	Small owner-controlled firms	Large owner-controlled firms	Small manager-controlled firms	Small owner-controlled firms	Small manager-controlled firms	Small owner-controlled firms
Cash flow ratio	0.0723** (2.42)	0.1044* (1.69)	0.0621 (0.74)	0.2070* (1.75)	0.1767*** (3.26)	–0.0423 (0.44)	0.1026 (0.81)	0.1344* (1.71)	0.1449 (1.04)
Sales-to-assets ratio	0.0248*** (2.80)	0.0330* (1.82)	0.0255 (1.45)	0.0328 (1.19)	0.0578*** (3.64)	–0.0075 (0.34)	–0.0002 (0.00)	0.0503*** (3.31)	0.0073 (0.24)
Δ *Working capital ratio*	–0.0136 (0.70)	–0.1328*** (2.59)	–0.0923** (2.24)	0.0844 (0.12)	–0.1464*** (3.08)	0.0405 (0.68)	0.2172 (1.22)	–0.1059*** (2.93)	0.1767 (1.01)
Bank loan ratio	0.0629** (2.20)	–0.0269 (0.73)	0.1994*** (3.21)	0.1549** (2.30)	0.0360 (1.58)	0.2263*** (3.79)	0.1818** (2.79)	0.2623*** (4.75)	–0.0445 (0.54)
Ownership concentration	0.0085 (0.35)	0.0160 (0.16)	0.0855 (1.12)	0.2324 (0.76)	0.0245 (0.26)	0.0695 (0.59)	0.2163 (0.68)	0.0940 (1.30)	0.1468 (0.47)
Firm size	0.0135 (0.91)	0.0019 (0.09)	0.1066*** (4.71)	–0.1034*** (3.40)	0.0153 (1.09)	0.1047*** (4.73)	–0.1053*** (3.50)	0.1200*** (6.99)	–0.2100*** (6.62)
Market concentration	–0.0034 (0.04)	–0.2115 (0.42)	1.9572* (1.66)	–2.1169 (0.93)	–0.2149 (0.44)	2.1688* (1.70)	–1.9054 (0.82)	1.9538* (1.66)	–4.0741 (1.60)
Number of firms	124	60	18	13	60	18	13	18	13
Observations (pooled)	496	240	72	52	240	72	52	72	52

Notes:

Heteroskedasticity-consistent 2SLS-Within regression estimates; absolute t-ratios in parentheses. Balanced panel with 342 fixed firm-specific and 3 fixed time-specific effects (coefficients not reported).

Instruments for Δ *Working Capital* : all other right-hand side variables, working capital ratio (t–1).

* significant at the 10% level (two-tailed test)

** significant at the 5% level (two-tailed test)

*** significant at the 1% level (two-tailed test)

Table 8 *Non Science-based Industries: Manager-controlled vs. Owner-controlled Firms*

Dependent variable: *Investment ratio*									
	Estimated coefficients	Coefficient difference			Estimated coefficients	Coefficient difference		Estimated coefficients	Coefficient difference
	Large manager-controlled firms	Large owner-controlled firms	Small manager-controlled firms	Small owner-controlled firms	Large owner-controlled firms	Small manager-controlled firms	Small owner-controlled firms	Small manager-controlled firms	Small owner-controlled firms
Cash flow ratio	0.1258** (2.01)	0.3921*** (2.99)	0.0300 (0.11)	0.0659 (0.34)	0.5179*** (4.49)	–0.3621* (1.68)	–0.3261* (1.70)	0.1558 (0.60)	0.0359 (0.11)
Sales-to-assets ratio	0.0199 (1.35)	0.0401 (1.51)	0.0579* (1.69)	0.0534 (1.30)	0.0600*** (2.71)	0.0177 (0.47)	0.0133 (0.30)	0.0777*** (2.52)	–0.0044 (0.09)
Δ *Working capital ratio*	–0.0506 (1.36)	–0.3881*** (3.11)	–0.0974 (0.56)	–0.1112 (0.78)	–0.4387*** (3.69)	0.2906* (1.79)	0.2768* (1.73)	–0.1480 (0.87)	–0.0138 (0.06)
Bank loan ratio	0.1094** (2.26)	0.2335*** (2.90)	–0.0317 (0.16)	0.5115*** (4.25)	0.3428*** (5.34)	–0.2652* (1.69)	0.2780*** (3.18)	0.0776 (0.40)	0.5433** (2.43)
Ownership concentration	0.0079 (0.14)	0.1657 (1.53)	–0.0034 (0.01)	7.0974*** (3.65)	0.1736* (1.87)	–0.1691 (0.37)	6.9316*** (4.56)	0.0045 (0.01)	7.1007*** (3.56)
Firm size	0.0240 (0.92)	–0.0086 (0.29)	–0.1715 (0.92)	–0.1001 (0.78)	0.0155 (1.06)	–0.1630 (0.88)	0.1086 (0.86)	–0.1475 (0.80)	0.2716 (1.22)
Market concentration	–0.1651 (0.31)	–1.018 (1.24)	–1.3514 (0.88)	2.3942 (1.33)	–1.1831* (1.90)	–0.3335 (0.21)	3.4121* (1.86)	–1.5165 (1.06)	3.7456* (1.67)
Number of firms Observations (pooled)	77 308	29 116	8 32	13 52	29 116	8 32	13 52	8 32	13 52

Notes:

Heteroskedasticity-consistent 2SLS-Within regression estimates; absolute t-ratios in parentheses. Balanced panel with 342 fixed firm-specific and 3 fixed time-specific effects (coefficients not reported).

Instruments for Δ *Working Capital* : all other right-hand side variables, working capital ratio (t–1).

* significant at the 10% level (two-tailed test)

** significant at the 5% level (two-tailed test)

*** significant at the 1% level (two-tailed test)

Endnotes

[1] See Schiantarelli (1996) and Weigand (1998) for surveys and discussion.

[2] Both variables are typically scaled by the beginning-of-the-year replacement value of total assets.

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

[4] The sources used are Commerzbank's, Wer gehoert zu wem?, Hypobank's *Wegweiser durch deutsche Aktiengesellschaften*, and Hoppenstedt's *Boersenfuehrer*.

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

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

[7] Of our sample firms 97 have more than one large shareholder and 21 more than three larger shareholders.

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

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

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

[11] See the recent surveys of Short (1994) and Shleifer and Vishny (1997) on corporate governance and firm performance.

[12] See Jensen (1986) for further discussion of management discretion.

[13] Estimating model (2) 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 (2), since based on *all* available observations, is efficient, whereas the estimates obtained from the two separate subgroups are not.

[14] See Baltagi (1995) on estimators for static panel data models. Since measurement error concerning investment opportunities is at issue, an instrumental variable approach like GMM (cf., e.g., Arellano and Bond, 1991) would seem to be a more appropriate estimation technique. However, the instrumenting technique calls for a long enough time series to render GMM estimation feasible. Unfortunately, our time series is rather short and additional degrees of freedom are consumed by constructing change rates etc. We have thus opted for the Within-estimator.

[15] 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 limited liability corporations are obliged by law to publish financial statements this shortcoming can not be overcome easily. Nevertheless future work should examine how the determinants of liquidity constraints vary systematically as firm size changes.

[16] Harhoff (1998) examines the link between firm size and R&D investment for a smaller sample of German firms. Haid and Weigand (1998) investigate the impact of governance structures and other firm characteristics on both R&D and tangible investment.

[17] This is consistent with the evidence in C. Weigand (1998) who reports a shift away of large corporations from bank financing in Germany since the early 1980s.

[18] 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.

[19] Regression model (2) is unaltered except for the dummy variable representing firm size rather than knowledge conditions.

[20] We defined four dummies: D1=1 for the large science-based firms (0 otherwise), D2=1 for the small science-based firms (0 otherwise), D3=1 for the large non science-based firms (0 otherwise), and D4=1 for the small non science-based firms (0 otherwise). To obtain the coefficient estimates for the large science-based firms and the coefficient differences between this subgroup and any other subgroup of firms, for example, we added three sets of right-hand side variables interacted with D2, D3, and D4 respectively to regression (1). Changing the baseline subgroup yields the estimates for the other subgroups.

[21] See Pagano and Roell (1998) for a recent theoretical analysis of these issues.