AN INFORMATION ECONOMICS PERSPECTIVE ON MAIN BANK RELATIONSHIPS AND FIRM R&D

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Abstract

Information economics has emerged as the primary theoretical lens for framing financing decisions in firm R&D investment. Successful outcomes of R&D projects are either ex-ante impossible to predict or the information is asymmetrically distributed between inventors and investors. As a result, bank lending for firm R&D has been rare. However, firms can signal the value of their R&D activities and as a result reduce the information deficits that block the availability of external funding. In this study we focus on three types of signals: Firm's existing patent stock, the presences of a joint venture investor and whether the firm has received a government R&D subsidy. We argue theoretically that all of these signals have the potential to alter the risk assessment of the firm's main bank. Additionally, we explore heterogeneities in these risk assessments arising from the industry level and the main bank's portfolio. We test our theoretical predictions for a sample of more than 7,000 firm observations in Germany over a multi-year period. Our theoretical predictions are only supported for firms' past patent activity while other signals fail to alter the risk assessment of a firm's main bank. Besides, we confirm that the risk evaluation is not randomly distributed across bank-firm dyads but depends on industry and bank characteristics.

Keywords: innovation, banking, information asymmetry

INTRODUCTION

The continuous generation of innovative products, processes and services is widely considered as the primary key for competitiveness and growth of firms as well as whole economies (e.g. Grant, 1996; Schumpeter, 1942). The major input of this innovation process is unique knowledge generated by investments in research and development. Interestingly enough, though, private firms have found it extremely difficult to obtain external capital for funding these crucial investments into their future. That limits the available funds to internal cash flows and scarce, highly selective venture capital investors (e.g. Levitas & McFadyen, 2009). Bureau van Dijk's ZEPHYER database records for example a yearly average of only 250 venture capital investments in Germany between 1998 and 2010, the 4th largest economy in the world with a population of roughly 2.5 million firms.

The situation is paradoxical as most managers and management research acknowledges the importance of knowledge production and innovation for firm performance (e.g. Grant, 1996; Leiponen & Helfat, 2010). Whole economies are casting strategies for entering the knowledge-based economy and reaping the benefits in terms of investment, employment and growth. Among the most ambitious is the European Union with its goal of becoming the most competitive knowledge based economy in the world through the Barcelona and Lisbon strategy plans. In reality, though, the knowledge-based economy finds itself without a mechanism for financing the underlying firm R&D investment. Several scholars have highlighted the need for bringing banks as the main provider of external financing back into the picture. The relevance of the topic is acknowledge in the US, e.g. through Nobel laureate Edmund Phelps (Phelps & Tilman, 2010), and in Europe (e.g. Peutz, Meeus, Nooteboom & Noorderhaven, 2010).

These shortcomings in capital markets are typically explained by the nature of R&D projects. They suffer both from information imperfections as well as asymmetries (for a comprehensive review see Hall, 2005). Information imperfections stem from inherent uncertainties about the technological as well as commercial viability of novel products for which no ex-ante probabilities of success exist (Amit, Glosten & Muller, 1990). Information asymmetries arise from the fact that firms possess superior knowledge about the value of their R&D projects compared with external investors (Ahuja, Coff & Lee, 2005). These investors, therefore, bear the extra risk of hidden information and hidden actions.

We develop theory based on the renewed interest in financing R&D and innovation both from strategic management (e.g. Levitas & McFadyen, 2009) as well as finance literature (e.g. Herrera & Minetti, 2007; Benfratello, Schiantarelli & Sembenelli, 2008). We adopt a novel perspective based on information economics theory by challenging the dominant assumption that all banks are equally subject to suffer from information asymmetries in financing private R&D projects. We acknowledge that banks cannot produce the relevant information on technological innovation themselves but they are uniquely positioned to aggregate the outcomes of the information production of other firms in the industry in the client portfolio, i.e. information externalities (Stiglitz, 2002) originating from heterogeneous client portfolios of different banks exist. We contrast this perspective by relying on portfolio theory which posits the opposite relationship: Correlated risks in specialized bank portfolios should make R&D investment in client firms less likely (Markowitz, 1991). Finally, we allow for a pro-active role of firms in signaling the value of their R&D activities to banks through patenting, obtaining government R&D subsidies or venture capital investments.

We test this theoretical framework empirically for more than 7,000 firm observations on R&D investments in Germany between 2002 and 2007. Unique access to the database of Germany's leading credit rating agency on the population of German firms and their main bank relationship allows us to construct novel variables on the overall portfolio of each of the firm's main bank. We have the rare opportunity to link this information to firm characteristics, R&D investment, patent statistics and venture capital investments based on a direct, non-heuristic link. The dataset is, to the best of our knowledge, unique in its breadth and representativeness for industry, firm and variable coverage.

The empirical results support our theoretical model. Firm R&D investment is higher if its main bank is either highly diversified or highly active in its particular industry. The information externality effect is limited to sectors in which uncertainties about commercial application are high. Firms can shift the threshold of a bank's risk considerations to lower levels of specialization if they can signal the value of their R&D activities through successful patent activities. Successful applications for government R&D subsidies and venture capital investments, though, are valuable in itself for firm R&D investment but fail to alter bank risk assessments significantly. Based on these findings, implications are derived for academic research, management and policy making.

The remainder of the article is structured as follows. Section 2, following this introduction, outlines our theoretical framework culminating in the derivation of hypotheses in section 3. In section 4 we present our empirical study including data, variables and methodologies. Section 5 presents the results of these analyses followed by derived conclusions in section 6.

THEORY

We choose information economics and related signaling theory as our main theoretical building blocks (e.g. Stiglitz, 2002; Ahuja et al., 2005). We will focus more precisely on its relevance for bank financing of private R&D activities. To achieve this we combine research from finance literature on bank lending decisions (e.g. Rajan & Zingales, 2001) with the literature on knowledge production through R&D. We start out by modeling the R&D investment decision of any given firm:

R&D (Industry characteristics, existing knowledge, funds)

The R&D investment decisions of a firm can be described as a function of the characteristics of its industry, its existing knowledge, and the available funds. The latter will be the center of attention for this study while the two former factors are largely treated as control variables[i]. We conceptualize a firm's available funds as a general liquidity pool from which a firm can draw financial resources for its R&D investment. We explicitly acknowledge that R&D investment competes with other firm functions (e.g. marketing) for these funds. The pool of available funds determines the cost of capital for a company. Firms will only invest in projects (R&D or other) if the expected returns exceed the cost of capital based on a net present value rational. The pool of funds has three primary components:

Funds (Internal cash flows, equity finance, bank loans)

Most firms rely on internal cash-flows for their R&D projects (Kim, Mauer & Sherman, 1998; Bond, Harhoff & van Reenen, 1999; Haid & Weigand, 2001; Harhoff, 1998). When it comes to external financing of innovations, venture capital financing has received a lot of attention in the literature (e.g. Gompers & Lerner, 2001a; Bottazzi & Da Rin, 2002; Audretsch & Lehmann, 2004). It is generally acknowledged that access to venture capital is constrained for the majority of firms because of limited availability and the highly selective nature of venture capital investors targeting few investments with the potential for high returns (e.g. Eckhardt, Shane & Delmar, 2006). Banks, though, as the primary provider of external financing for the vast majority of firms appear ill-equipped to finance R&D investments (Bozkaya & Potterie, 2008).

Assuming a perfect market for capital, financing R&D investments should not be different from any other investment decision and firms should opt for all projects with a positive net present value (Modigliani & Miller, 1958). However, the assumption does not hold because of the nature of R&D (for recent reviews see Hall, 2005 and Hall, 2009). The outcomes of R&D are generally uncertain. This uncertainty has two primary dimensions (Amit *et al.*, 1990). First, there is a substantial degree of technological uncertainty about the success of an R&D project. Materials and procedures are almost by definition new and largely untested. Probability distributions for the success of an R&D project are difficult or even impossible to predict at the early stages (Hall, 2005). R&D investments provide very little collateral. Half of all R&D expenditures finance wages for skilled scientists and engineers (Hall, 2005). Investments in physical research assets and laboratories are often times highly specific to a firm or even a project making it difficult to re-deploy, sell or use for others (Herrera & Minetti, 2007). Secondly, there is an important degree of uncertainty about whether the firm will be economically successful with its technologically new products and processes. A significant proportion of product innovations end up as economic failures because they do not meet customer needs or competitors are quick in their imitation or substitution activities eroding margins from the pioneering advantage (Dos Santos & Peffers, 1995; Gourville, 2006).

However, research shows that these underlying uncertainties are not equally exogenous to managers and external capital providers. Endogenous uncertainty can be overcome by firm activities over time while exogenous uncertainties exist independently from any firm actions (Folta & O'Brien, 2004; Cuypers & Martin, 2009). Firms perform R&D to resolve endogenous uncertainties through experimentation, testing and simulation. In that sense, R&D is a sequential process in which firms uncover information and reduce endogenous uncertainty with each step of the process (Roberts & Weitzman, 1981). There is a long time span between the start of an R&D projects and the appearance of revenues from it, i.e. when the uncertainty is ultimately resolved and success or failure is visible to actors outside of the firm. Empirical estimates predict this time duration between 4 and 5 years with significant industry differences (e.g. Pakes & Schankerman, 1984). Hence, firms have significant time advantages in discovering potentials or failures within R&D projects compared to external partners for which the same uncertainties remain exogenous. The result is an information asymmetry that insiders can exploit (Aboody & Lev, 2000, Ahuja et al., 2005).

Banks are even more disadvantaged in this situation compared to equity investors because their opportunities for directing/monitoring the use of their funds is limited and they do not benefit from profits that may result from it beyond the contractually fixed interest rate (Hennart, 1994). Besides, all banks are equally constrained by law and regulation in their lending decisions by their institutional environment (e.g. Bank for International Settlement, 2005).

Financing R&D investments is therefore characterized by a combination of information that is either not available (exogenous uncertainty) or asymmetrically distributed between the firm and its external capital providers (endogenous uncertainty). Appropriate risk premiums for individual borrowers cannot be assessed (Stiglitz, 2002) and firms find themselves credit constrained because banks will only set high, average risk premiums (Aghion, Fally & Scarpetta, 2007). As a result, the pool of funds available for R&D investment in a firm is deprived of bank financing.

An emerging stream of literature from finance and strategic management begins to emphasize heterogeneities among banks and firm’s signaling. The literature on banks and innovation financing is still scarce. Positive relations have been found for the development of the regional banking system (Benfratello et al., 2008) and relationship length (Herrera & Minetti, 2007). Negative relationships stem from government ownership of banks (Sapienza, 2004; Haselmann, Katharina & Weder di Mauro, 2009). Levitas et al. (2009) contribute to strategic management literature. They find the value of signaling (through patents and distribution agreements) for overcoming financial constraints in small firms through attracting venture capital investors.

HYPOTHESES DEVELOPMENT

All of the theory presented so far rests on the important assumption that all banks draw from identical pools of information and should therefore suffer from identical degrees of information deficits. We question this assumption and argue that information between banks is distributed asymmetrically between banks, too. We concede that the specific uncertainties related to R&D investments of a particular firm are equally exogenous to all banks. However, information is produced by other firms in the same industry on technological feasibility as well as market success. At least parts of the uncertainties are therefore endogenous to these firms. We argue that banks are heterogeneous in their ability to access this information based on information externalities from the composition of their existing client portfolio. What is more, we will lay out the opportunities for the focal firm i to signal the value of its R&D activities and influence the availability of bank financing.

Information externalities from a firm’s main bank client portfolio

Banks differ in their level of engagement with client firms. Boot et al. (2000) present a dichotomy of bank lending with varying levels in between. Transaction lending is closely related to brokerage activities where it is sufficient for the bank to lend based on a standardized transaction. Relationship lending, though, requires borrower specific information in activities such as screening and monitoring (for a review see Boot, 2000). The relation specificity can provide them with access to private data about the financed firm which can lead to a quasi monopolistic banking position and superior benefits from future business with the particular client (Boot & Thakor, 2000). We will focus on a specific relationship, i.e. a firm's main bank, defined as the bank that a firm considers its primary source for all banking services. Within all relationship lending, main banks are uniquely positioned for information acquisition about their client firms (Herrera & Minetti, 2007).

We construct a simple theoretical model to investigate the effect of the client portfolio of a firm's main bank on the firm's R&D investment which can be easily extended. We assume two identical firms i_s and j_s. Both operate in industry s. Bank A is the main bank of firm i_s, bank B is the main bank of firm j_s. Banks A and B are identical, except for their client portfolio. Each bank has only two firms in its portfolio. Bank A's portfolio consists of firm i_s and identical firm k_s which operates in the same industry; for short $P_A(i_s, k_s)$. It is further assumed that industry s consists only of three firms i_s, j_s and k_s. Bank B's portfolio encompasses firm j_s and identical firm l_t from a different industry t; in short $P_B(j_s, l_t)$.

We will develop a purely comparative argument for the R&D investments of firms i_s and j_s. We make the following assumptions: All firms have equal propensities to invest in R&D. The underlying uncertainties and adverse selection problems for the particular R&D investments are identical for bank A and B. They are fully exogenous to each bank. However, the portfolio composition can provide bank A with an information advantage over bank B. Firms can overcome endogenous uncertainties through various forms of R&D, market research, prototyping, simulations, etc. All firms reveal information to their main banks through their transactions and loan applications. Substantial parts of this information can be expected to be private and not available to the general public. This can include competitive interactions, future product and market plans as well as revenue streams (Boot & Thakor, 2000). It is important to note that the private information is produced by the individual firm and only aggregated by its main bank which is uniquely positioned to do so. The bank does not necessarily learn in the narrow sense of exploring causal relationships but benefits from information externalities based on its client portfolio (Stiglitz, 2002). It is an externality because the bank does not directly and economically reimburse its other clients for the provision of this particular information. Hence, bank A and bank B draw from different pools of information in their lending decisions. The bank with the more relevant information can be expected to be in a position to assess risk premiums for individual firms more accurately compared to the general, high risk premium. As a result more funds would be available to its clients and, all other things being equal, the firm doing business with this bank should be able to invest comparatively more in R&D.

The relevance of the information externality of the main bank for firms i_s and j_s is the highest if the information stems from a similar technological and market context, i.e. from competitors in the same industry (Dussauge, Garrette & Mitchell, 2000). Hence, $P_A(i_s, k_s)$ can be expected to deliver more relevant information externalities than $P_B(j_s, l_t)$ because bank A can obtain information from firm k_s which operates in the same industry as i_s. Given that the pool of relevant information is finite, i.e. all firms in a given sector, a bank that has comparatively more of these firms as its clients is more likely to benefit from information externalities. Hence, information asymmetries between bank A and bank B emerge from their market share with firms in sector s.

In a typical loan application process a bank will benchmark the information of a prospective borrower against key figures from its other clients from the same sector. This comparison is often times based on information stemming from other lending contracts which is not publicly available. The quality of these benchmarks is expected to be higher for banks that draw from a larger pool of industry information compared to banks with a comparatively narrower pool. In theory, firms could be expected to avoid certain banks in the first place because of the danger of unintended knowledge spillovers to competitors. However, in reality strong safeguards are in place to prevent banks from revealing information about one client to another. The penalties would be high both in terms of legal liabilities as well as reputational losses (e.g. Degryse & Ongena, 2001). We propose:

> Hypothesis 1: R&D investment of a firm increases with the degree of market share of its main bank's corporate client portfolio in its industry.

However, the degree of specialization of its client portfolio is not an isolated information provision tool for the bank. A high degree of specialization in one industry would also imply that the risks involved from the technology or market side are highly correlated. This follows a basic rational that banks manage the risks originating from their clients not individually but for the portfolio as a whole (Markowitz, 1991). Banks can reduce the systemic risk of the overall portfolio by combining uncorrelated risks (Markowitz, 1952). Following this portfolio theory logic, $P_A(i_s, k_s)$ contains more risk than $P_B(j_s, l_t)$ because the risks originating from firms j_s and l_t can be expected to be less correlated since they operate in different sectors, i.e. market and technology environments. Bank A can be expected to demand a higher risk premium from its client i_s compared to bank B from j_s solely based on the risk exposure of its portfolio. As a result, available funds for i_s should be comparatively lower, resulting in less R&D investment. We suggest:

> Hypothesis 2: R&D investment of a firm decreases with the degree of specialization of its main bank's corporate client portfolio in its industry.

Hypotheses 1 and 2 are not mutually exclusive. The former is denominated by the size of the industry the latter by the size of a bank's client portfolio. Banks with a small portfolio can easily have a portfolio being dominated by clients from a single industry (i.e. high degree of specialization) while these clients are only a small fraction of all firms in the industry (i.e. the bank has a low market share in the industry). The information externality logic suggests that banks benefit from every additional firm that they can add to their client portfolio equally. However, the aggregation of information from a bank's portfolio entails costs for the bank. These are especially high if the information is dispersed and hence difficult to screen (Koput, 1997). This effect is most pronounced if a bank is highly diversified across a large number of industries, i.e. the degree of portfolio specialization is low. Information screening becomes increasingly effective and efficient if fewer industry information domains have to be covered. Information processing in a bank can be expected to be especially productive if it draws from a large pool of information based on a high market share in an industry and a high degree of specialization in this industry making the screening of the information more efficient. A bank with these characteristics should possess superior information for setting adequate risk premiums for its clients in the particular industry. This in turn, should enable these client firms to invest comparatively more in R&D. We put forward:

> Hypothesis 3: R&D investment of a firm increases if its main bank has both a high market share in its industry and a high degree of specialization of its main bank's corporate client portfolio in its industry, i.e. there is a positive moderating effect.

Finally, the degree of uncertainty (both exogenous and endogenous) is not equally distributed across all industries. Especially, at the "research" stage which is not yet directed at a particular product, technological and market potentials are highly uncertain compared to the "development" stage in which potential revenue streams are beginning to emerge (for a recent review see Czarnitzki, Hottenrott & Thorwarth, 2011). It can take several years between the start of an R&D project and the generation of economic returns (e.g. in pharmaceuticals) or just several months (e.g. in service sectors where production and consumption is almost instantaneously) (Berry, Shankar, Parish, Cadwallader & Dotzel, 2006). Hence, the level of uncertainty of innovation activities in an industry is a function of the time it takes for an R&D project to be ready for application. This distance to application has often been linked to the importance of scientific knowledge from universities which is closer to academic research and further removed from industrial commercialization (e.g. Siegel, Waldman, Atwater & Link, 2004; Agrawal, 2006). Cohen, Nelson & Walsh (2002) identify important differences between industries in the usage and importance of academic knowledge. We argue that the distance to application increases the uncertainty of the innovation activities in an industry. This increases in turn, the potentials for benefitting from information asymmetries because the final resolution of fundamental uncertainties through observable market success is further removed in the future. At the same time, the risk of financing R&D increases if potential revenue streams are further delayed in the future (Czarnitzki et al., 2011). We conclude:

> Hypothesis 4: The positive effects of main bank industry market share and the negative effects of main bank industry specialization on firm R&D investment are higher in industries which rely heavily on knowledge from scientific sources.

Signaling through reputation and legitimacy

So far we have only considered mechanisms on the bank-side and their ability to overcome information asymmetries through externalities. However, firms have additional opportunities to overcome the information asymmetries by signaling the value of their R&D activities. We follow Ndofor et al. (2004) and define a signals as "conduct and observable attributes that alter the beliefs of, or convey information to, other individuals in the market about unobservable attributes and intentions (p.688)". This is a deviation from the theory outlined in the previous section as firms i_s and j_s in the model are no longer considered to be identical. They differentiate themselves through firm specific signaling. A credible signal will allow a bank to provide a more accurate risk assessment on a firm's R&D investment, resulting in more available funds and subsequently increased R&D investment. We will explore signals based on firms past actions (patenting) as well as legitimacy that can be transferred from ties to established actors and institutions (government R&D subsidies and venture capital investors).

The value of signaling through past actions is rooted in theory on firm reputation (Rindova, Williamson, Petkova & Sever, 2005). Levitas et al. (2009) investigates the value of patents as signals for attracting venture capital investors and supports it for a sample of firms from the pharmaceutical industry. Patents provide a tangible representation of a successful innovation. Besides, the patent office requires a certain degree of novelty in order to grant a patent (Encaoua, Guellec & Martinez, 2006). The existence of a patent allows therefore also inferences about the quality of the underlying R&D. Patents can be interpreted as signals for future revenue streams. These may come from possessing a temporary advantage on the product market or through generating license fees (Levitas & McFadyen, 2009). Hence, the risk concerns of a main bank based on correlated risks in its client portfolio should be reduced.

Other potential signals are not rooted in a firm's past actions but in being associated with authoritative actors (Rindova *et al.*, 2005). This perspective is rooted in institutional theory. Organizations can gain legitimacy and hence access to resources through external validation in establishing institutional linkages with established institutions or succeeding in contests

(Baum & Oliver, 1991; Rao, 1994). We focus predominantly on the ability of a firm for attracting external funds for R&D, more precisely government R&D subsidies and venture capital investment. Venture capital investors are known to be highly selective in their investment decisions (Eckhardt *et al.*, 2006). They monitor firms intensely, set growth/performance oriented contracts, facilitate crucial personnel decisions and provide additional services (e.g. access to strategic alliances) (e.g. Gompers & Lerner, 2001b). As a result, the chances that the firm will be successful in the future and generates positive returns should increase. Banks should therefore be able based on this signal to provide additional funds for the firm and its R&D investment. Similarly, many governments provide R&D grants for firms to stimulate R&D investment. Information requirements in applications are high and competition for grants is intensive (Czarnitzki & Toole, 2007). Successful grant awards are highly selective and can signal the exceptional value of an R&D project (Aerts & Schmidt, 2008; Kleer, 2010). Banks may therefore rely on this external assessment for overcoming information asymmetries.

We propose:

> Hypothesis 5: R&D investment of a firm increases with the degree of market share of its main bank's corporate client portfolio in its industry and this effect is reinforced by the patent stock of the focal firm, the presence of a venture capital investor or a government R&D subsidy, i.e. there is a positive moderating effect.
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> Hypothesis 6: R&D investment of a firm decreases with the degree of specialization of its main bank's corporate client portfolio in its industry but this effect is mitigated by the firm's patent stock or if the

focal firm attracted a venture capital investor or received a government R&D subsidy, i.e. there is a positive moderating effect.

EMPIRICAL STUDY

Data

We construct a unique panel dataset for testing the theoretical predictions. Data requirements are high because comprehensive information is required for banks and their client portfolio across multiple industries. What is more, the bank information needs to be linked to firm R&D investment. We achieve this by linking multiple databases in Germany. The crucial starting point is the Mannheim Enterprise Panel (MUP).

It is a firm-level database collected by Creditreform, the leading credit rating agency in Germany. Since 1999, ZEW receives twice a year a full copy of Creditreform's data-warehouse of firm level data and constructs the panel. Creditreform collects its data based on regional firm registries. It covers nearly the entire population of 2.5 million German firms with few exceptions that are not legally required to register with the authorities (e.g. farmers). The Creditreform data is also the German input for the widely used AMADEUS database. Creditreform provides credit information and insurance services based on its data. Hence, it covers information that allows assessing a firm's credit worthiness. Most importantly for our study, it contains firms' bank relations including the bank that firms consider as their main bank. Data quality can be considered as high since keeping information on financial solvency and relationships current is a core part of the business model of Creditreform and firms are not overly concerned with revealing their bank relationships (similar information could be found on a typical invoice). Given the population character of the database, we can calculate the industry composition of each bank's client portfolio. The bank information is very precise based on the German eight digit bank code which allows a precise identification of the banks' location and type (e.g. private bank vs. savings bank). Based on this information, we can track 2,432 banks. The banking code is mandatory for banks in German in obtaining a banking license. Coverage is therefore not limited. It should be acknowledged that the database does not contain information on the extent of each bank's lending engagement with individual firms. No such database is to the best of our knowledge publicly available or accessible.

We link this dataset to the "Mannheim Innovation Panel" (MIP) which provides information on firm R&D investment; the dependent variable of our analyses. The dataset is drawn as a representative, stratified random sample based on the German MUP firm population. In contrast to other studies analyzing bank based financing for innovation we can therefore form perfect matches between the two databases, i.e. we do not have to rely on regional banking indicators (e.g. Benfratello et al., 2008) or statistical matching. The MIP survey is conducted annually by the Centre for European Economic Research (ZEW Mannheim) on behalf of the German Federal Ministry of Education and Research. For our study we use data from the 2002 till 2007 surveys and analyze 7,294 firm observations from 4,363 firms. The panel is unbalanced.

The MIP survey targets R&D decision makers. These can be heads of R&D departments, innovation managers or CEOs which is most likely the case in smaller firms where no elaborate functional structures exist. Several mechanisms are in place to secure the quality of the survey and its results. All core constructs in the survey follow the OECD's "Oslo Manual" on measuring innovation inputs, outputs and processes (OECD, 2005). Furthermore, the MIP is the German contribution to the Community Innovation Survey (CIS) of the European Union. CIS methodology and questionnaires have been refined over the years in international application. They are subject to extensive pre-testing and piloting in various countries, industries and firms with regard to interpretability, reliability and validity (Laursen & Salter, 2006). This multinational application of CIS surveys guarantees quality management and assurance. CIS data have been the basis for several recent publications in highly ranked management journals (e.g. Laursen & Salter, 2006; Leiponen & Helfat, 2010).

The merged dataset contains precise identifiers for the European Patent Office statistics as well as the Bureau van Dijk ZEPHYR since it is also the basis for the AMADEUS database. The former linkage allows us to obtain the number of patents granted to each firm, the second one tracks venture capital investments. The final dataset contains 7,294 observations from 4,363 firms between 2002 and 2007 encompassing firm, innovation and R&D characteristics, bank information, patent activity and venture capital investments.

Empirical model

Dependent variable

Our dependent variable is R&D investment measured as the share of R&D expenditures on total sales. This R&D intensity measure is frequently used to put into account size effects (e.g. Cohen & Levinthal, 1989).

Independent variables

We calculate for each firm the composition of the client portfolio of its main bank in its industry. We define the industry for this matter at the two-digit NACE level for an aggregation that is neither too coarse nor too narrow, e.g. NACE34 covers firms in the automotive sector including OEMs and suppliers but not other transportation equipment. Based on this aggregation, a bank portfolio can be described along 84 different industry dimensions. We calculate the market share of a firm's main bank in an industry as the share of firms in the focal firm's industry in its client portfolio divided by all firms in this industry in Germany. This follows the basic rational that all firms in an industry are the total pool of information a bank can potentially draw from. We measure specialization as the share of firms in the focal firm's industry of the total portfolio of a firm's main bank portfolio. To account for differences in firm size we include the number of employees as weights in the calculations of the shares. This should be considered as a proxy in the absence of detailed bank lending information for all firms. Individual lending information for each bank and its clients would be preferable. However, after consulting with industry experts we conclude that banks are highly unlikely to share this information due to confidentiality and competition concerns. The coefficients of the main bank market share and specialization variables test hypotheses 1 and 2 respectively. We test hypotheses 3 through a multiplicative interaction of both variables, i.e. whether the specialization of a banks client portfolio in and industry where it has a large market share has an additional effect.

For the test of hypotheses 4 we construct a variable at the industry level capturing the use of scientific knowledge. Cohen et al. (2002) construct a similar variable based on the Carnegie Mellon innovation survey. We follow their approach and access the equivalent survey for Germany conducted in 2001, one year ahead of our observation period. The particular survey question asks heads of R&D departments about external knowledge sources that were important for their innovation activities during the preceding three years. Question layout and design is well established in strategic management research on firm's knowledge search (e.g. Laursen & Salter, 2006; Leiponen & Helfat, 2010). The survey is representative for the German firm population and we obtain projected values for how many firms in an industry used knowledge from universities and/or research institutes. We include the variable as a main effect in the model and split the sample in two sub-samples with above/below average use of scientific knowledge in the industry. Hypothesis 4 would be supported if the effects from a main bank's market share and specialization are stronger in the above average sub-sample.

Hypotheses 4 and 6 suggest effects from patenting, government R&D subsidies and venture capital investment. We add the EPO patent stock for each firm to the model (scaled per employee) and a dummy variable for the presence of a venture capital investor. The MIP survey provides information on whether the firm has received a government R&D subsidy at the European, federal or regional level. We include a dummy variable indicating whether this is the case or not.

Our theoretical model predicts several relationships based on the "ceteris paribus" assumption. We add several control variables to ensure unbiased results. At the bank level we control for the type of bank. The structure of the German banking system is often described as the "Three Pillar System" (see e.g. Krahnen & Schmidt, 2004; Engerer & Schrooten, 2004) and consists of state owned savings banks (in German: "Sparkassen"), cooperative and private banks. All these banks are active as universal banks. However, there is evidence that private banks differ in their decision making, e.g. compared to government owned banks (Sapienza, 2004; Porta, Lopez-de-Silanes & Shleifer, 2002). Hence, we add a dummy variable indicating whether the firm's main bank is a savings or cooperative bank. Similarly, banks may differ in their size and regional orientation because investments have been found to be more likely in geographical proximity (Coval & Moskowitz, 1999; Grinblatt & Keloharju, 2001). We add control variables for the total client corporate client portfolio of a firm's main bank (number of firms weighted by employees in logs) as well the share of client firms located in the same agglomeration area.

Firms may work with multiple banks which can in turn alter their relationship with the main bank (Boot & Thakor, 2000). Hence, we add the number of other banking contacts of a firm as a control variable to the model. Relationship length between a bank and its client has also been found to alter lending decisions (Herrera & Minetti, 2007). The overwhelming majority of the firms in our sample (86%) never change their main banking relationship during the 5 year observation period. Hence, an exact measure of relationship length appears ill suited. Conversely, we add a dummy variable indicating whether the firm has changed its main bank in the preceding three year period. We proxy firm's internal cash flow through the return on sales from the previous year and its overall creditworthiness through its credit score. Creditreform determines the credit score as an index based on a proprietary formula which puts heavy penalties on negative events such as delayed payments to suppliers or insolvency. All indices are standardized to ensure comparability. Besides, firms that are traded on the stock exchange have broader access to external financing. We control for this effect by adding a dummy variable for whether the firm is incorporated based on stock market shares.

Other factors may influence firm R&D decisions. Firms can suffer from liabilities of size or newness in their resource acquisition (e.g. Shinkle & Kriauciunas, 2009). We add firm size (number of employees in logs) and firm age (number of years since founding) to the model. Firms can also be part of a larger group and draw from its resources. Hence, we add a separate dummy variable for such cases. Finally, we capture remaining industry differences by including industry dummy variables. They follow grouped two-digit industry classes as suggested by OECD and Eurostat. The resulting groups are low-tech, medium low-tech, medium high-tech and high-tech manufacturing as well as low knowledge intensive and knowledge intensive services (see Appendix A for full details). Similarly, we add an additional control dummy for a firm's location in East Germany which has been found to provide different geographical opportunities and challenges compared to West Germany as a result of re-unification (e.g. Czarnitzki, 2005).

Estimation model

A logical inference from our theoretical reasoning is that some firms may not be able to invest in R&D at all, i.e. their R&D investment equals zero. Hence, a technique is required that takes into account that the dependent variable is censored at zero. We estimate censored panel regression models. In particular we estimate random effects tobit models. Fixed effects tobit models are only beginning to emerge and existing approaches have been criticized for delivering inconsistent estimates as well as being overly demanding on assumed data and variation (Cameron & Trivedi, 2005; Grimpe & Kaiser, 2010). The inconsistency stems primarily from the finite nature of empirical samples. Non-linear, fixed effects models suffer especially from inconsistency issues because estimates are more likely to be influenced by incidental parameters (Heckman, 1987; Neyman & Scott, 1948). Inconsistencies can be assumed to be reduced if the sample encompasses more than eight time periods but random effects estimators are more commonly used (Cameron & Trivedi, 2005). Given our data availabilities we opt for a random effects model. We run several model specifications and include the independent variables of interest stepwise.

We inspect the dataset for multicollinearity based on correlations and variance inflation factors and find no evidence by any conventionally applied standard (e.g. Chatterjee & Hadi, 2006). The mean variance inflation factor equals 1.63 with the highest individual variance inflation factor equaling 3.94 (see Appendix B for full details). Table 1 provides descriptive statistics for the sample as well as a comprehensive overview on variable observation levels and scales.

Insert Table 1 about here

RESULTS

Main bank specialization and market share

Table 2 presents the estimation results of the tobit models testing hypotheses 1 and 2. Model 1 contains only control variables and can serve as a benchmark for all other models. Significant effects remain stable across models and the quality of model fit increases (log likelihood and Chi squared test).

Insert Table 2 about here

Model 2 includes the main effects of bank specialization and industry market share. The effect of bank specialization is negative and highly significant, lending support to hypothesis 1. A bank's market share in the focal firm's industry has a positive and highly significant effect on R&D investment. Hence, hypothesis 2 is supported, too. We calculate effect sizes based on a one standard derivation difference from the average in main bank industry specialization and market share. The former reduces firm R&D intensity by 14%, the latter increases it by 6%. Hence, the effects are not just significantly different from zero but have also a sizeable impact on firm R&D. This result reinforces the theoretical logic that both portfolio and information externality theory can inform predictions on firm R&D investment through the main bank's client portfolio. Diversification in firm's main bank portfolio allows for more firm R&D spending while the increasing industry specialization within a bank's portfolio allow for less. We test a simultaneous relationship by adding a multiplicative interaction term between bank specialization and market share in model 3. Interestingly, there is no immediate relationship between the two variables beyond the main effects. As a result, neither mitigating nor reinforcing effects can be found and hypothesis 3 has to be rejected.

In hypothesis 4 we develop a theoretical argument for the effects to differ depending on the uncertainty in industry innovation activities depending on how distant they are to application.

The latter is proxied through the importance of scientific knowledge for innovation in an industry which has a consistently positive and significant effect on firm R&D investment in Table 2. We test hypothesis 4 by splitting the sample along the mean of the industry share of firms that use science as an input in their innovation activities. Table 3 shows the estimation results for both sub-samples. The negative effect from bank specialization remains significant in both samples, however the significance level drops strongly in the sub-sample with industries that use less scientific knowledge. Conversely, the information externality effect appears to be confined to industries with an above average use of scientific knowledge. Hence, hypothesis 4 is partially supported. Additionally, we test the significance of the multiplicative interaction effect between bank specialization and market share suggested in hypothesis 3 for the two sub-samples, too. There is no additional significant finding. Models are not reported.

Insert Table 3 about here

Signaling effects

We have developed hypotheses on three kinds of signals firms can send to their main banks: Patents, government R&D subsidies and venture capital investments. The main effects of all of these factors are positive and significant. This is fully in line with existing research emphasizing complementarity effects of R&D with existing knowledge stocks embodied in patents (e.g. Cohen & Levinthal, 1989) as well as additionality effects from government R&D subsidies (e.g. Aerts & Schmidt, 2008) and growth oriented venture capital investments (e.g. Levitas & McFadyen, 2009). However, the signaling effect that these factors may have on a firm's main bank is novel. We add separate multiplicative interaction effects with each factor and bank specialization in models 4, 5 and 6. We use separate models for each interaction to avoid potential issues arising from multicollinearity. Table 4 shows the results for these models.

Insert Table 4 about here

All main effects remain stable. Only the interaction effect between a firm's patent stock and its main bank's degree of portfolio specialization is positive and significant (Model 4). There are no additional significant interaction effects for firms having attracted a venture capital investor or received a government R&D subsidy (Model 5 and 6). All of the signals fail to alter the positive effects from information externalities of a bank's market share. In sum, hypothesis 5 is rejected. Hypothesis 6 is only supported for a firm's patent stock. Our result are in line with Levitas & McFadyen (2009) who identify a similar positive patent effect for the venture capital market. In conclusion, the proposed signaling effects are limited to reputation effects based on the success of firm's past patenting success. Hence, the signaling effect is firm specific and based on past innovation outcomes. Input oriented signals originating from successfully attracting government R&D subsidies or venture capital fail to alter the risk assessments or information position of banks. We suspect that this is due to the fact that they are general in nature and can be interpreted positively even without in-depth industry experience of a bank.

Control variables

All models contain an identical set of control variables. Their influence on firm R&D intensity is consistent across all models with regard to significance levels and directions. We have not developed theoretical predictions for any control variables but significant effects should be discussed briefly. First, it is noteworthy that out of all control variables at the bank level only the type of bank has a significant influence on firm R&D investment. An average firm working with a savings or cooperative main bank invests significantly less in R&D. This result supports other studies (Haselmann et al., 2009) which emphasize the inefficiencies in bank decision making induced by political influence through government ownership (Porta et al., 2002; Sapienza, 2004). R&D intensity increases with firm size but decreases with firm age. Similarly, incorporated firms having access to the stock market invest more in R&D. This provides evidence for the close relationship between overall resource availability for R&D investments (Ahuja, Lampert & Tandon, 2008) as well as R&D as part of a growth strategy for young firms (King & Levine, 1993). Similarly, the negative relationship between return on sales and R&D investment can be interpreted as an investment into generating the potential for future revenue streams in which the positive performance effects of current R&D are on average 4 to 5 years removed (Pakes & Schankerman, 1984). The significant industry dummies (low tech manufacturing is the reference group) indicate that the R&D investment is a direct reflection of technological opportunities and competitive pressures. It increases with the knowledge intensity of the industry both in manufacturing and services. Low knowledge intensive service sectors such as transportation are the exception reflecting fewer technological opportunities (e.g. Lyons, Chatman & Joyce, 2007).

CONSISTENCY AND SENSITIVITY CHECKS

We estimate several additional empirical specifications to demonstrate the robustness of our findings. Appendix C shows the results. First, we investigate potential effects from the model choice. We replace the tobit specification with an ordinary least squares regression in Model 4. The core findings on the effects of main bank market share and sector specialization remain intact. All other consistency check models are again based on the original tobit model for comparison with the main model. Secondly, we follow up on the results of the control variables regarding significant differences for savings and cooperative banks. We have dedicated controls for bank size and geographic scope in every model. However, banks may also differ in their structure. Especially private banks (e.g. Deutsche Bank) are organized as national branch systems with central headquarters. Hence, they can benefit from accessing the knowledge pool/risk diversification of the group as a whole. We recalculate all portfolio variables at the group level and estimate separate models for savings and cooperative banks (Model 5) as well as private and national banks (Model 6). Our core findings remain stable in both groups indicating that the effects are not dependent upon assumptions on the aggregation level of the banks or limited to certain bank types. Thirdly, our sample split in Table 3 shows that the effects from the positive effects originating from information externalities on firm R&D investment are limited to sectors in which science is an important source for innovation. In an alternative operationalization we capture the latter based on the OECD classification for the R&D intensity of certain sectors (Appendix A). Within this framework, sectors are classified based on the ratio of firms that perform R&D continuously. Continuous R&D activities imply that the value of knowledge production is long term and accumulative in certain sectors but rather transitory in others. We assume that the former sectors are closer to the scientific knowledge production than the latter and test it by splitting the sample based on the OECD classification. Model 7 shows the estimation results for low technology industries encompassing low-tech manufacturing as well as low knowledge-intensive services. Model 8 presents the equivalent estimation results for high-tech industries which include medium- as well as high-tech manufacturing and knowledge intensive services. The results support our main finding that the described effects in hypotheses 1 and 2 are largely confined to high-tech sectors. We can no longer identify the significant negative effect from main bank industry specialization on firm R&D outside of science based industries (Table 3) when compared with the low-tech industry classification in Model 8. Finally, our theoretical argument is strictly comparative in nature and combinations of firms and their main bank are assumed as given. This is largely in line with our descriptive statistics indicating that 85% of the firms in our sample never switch their main bank during the six year observation period. Nevertheless, firms and banks have made choices on this relationship at a certain point in time but this selection is unobservable to us. In order to test, whether the bank choice is correlated with the error term and may therefore bias the results we estimate an additional instrument variable tobit model. The only bank choice variable available to us is whether the firm has changed its main bank in the preceding three years. We use this variable as the dependent variable in the first stage equation of the instrument variable estimation (Model 9). We rely on two regional variables (district level) as instruments. We argue that the economic development of a region provides firms as well as banks with more choice options. Hence, we use district GDP and then number of bank branches within a district (in logs) as instruments. The instruments are jointly significant at the 98% significance level; the number of bank branches is also individually significant. We conduct an additional Sargan test on potential overidentification which is rejected. Model 10 contains therefore the tobit estimation results with the bank change being instrumented. Estimation results on our main hypothesis tests remain stable. In sum, we are confident that our empirical analyses provide reliable tests for our theoretical framework.

CONCLUSIONS AND FUTURE RESEARCH

In this study we question the general assumption that all banks suffer to the same degree from information deficits or asymmetries when providing funds for R&D intensive clients. We concede that banks cannot produce the necessary technological information themselves but they are uniquely positioned to benefit from the information production of the firms in their client portfolio. Hence, they can benefit from an information externality which becomes important if the information is relevant for the technological and market environment of its clients, i.e. the bank has a large market share in the client's industry. We contrast this effect with portfolio considerations and predict a negative relationship between a firm's R&D investment and the industry specialization of its main bank. These theoretical predictions are supported by our empirical test for Germany based on a dataset that is to our knowledge unique in terms of variable coverage, representativeness and comprehensiveness. It also allows us to test whether the effects are equally pronounced in all industries. We find that the positive effect from information externalities is confined to high-tech industries in which academic research is a major source of knowledge. We have argued theoretically, that this is due to increased uncertainties if innovation activities are further removed from commercial application. With regard to the signaling that the firm can provide itself about the quality of its R&D, we find that only patents provide valuable signals to banks but not government R&D subsidies or venture capital investments. These findings have major implication for academic research as well as practical management and policy development.

From a scientific perspective we are able to contribute by connecting research in finance and strategic management. On the finance side, there exists an increasing, recent interest in financing firm innovation and growth (Herrera & Minetti, 2007; Benfratello et al., 2008) in which findings from current strategy literature have been largely absent. Conversely, strategic management literature has been heavily focused on venture capital investments (Levitas & McFadyen, 2009) for firm innovation while largely ignoring that these selective investments are dwarfed by the importance for bank financing for the vast majority of firms in most modern economies (Phelps & Tilman, 2010). We see our theoretical combination of information externality and portfolio theory as a valuable extension for both research streams because it provides a novel, differentiated perspective on the largely acknowledged root cause of information availabilities and asymmetries. What is more, we identify both opportunities as well as boundaries for firm signaling important external partners such as banks. Especially the boundary conditions of ineffective signals are to our knowledge largely unexplored in the literature (e.g. Levitas & McFadyen, 2009).

Our theoretical and empirical findings are strictly comparative in nature and interpretations on opportunities for active search and selection (either through banks or firms) have to be made carefully. We find clear evidence that a firm's main bank makes a significant difference in the availability of funds for R&D investment. Hence, it follows only logically that firms should be better off working with highly diversified banks. The positive effects from working with leading banks in a firm's industry are limited to sectors in which the underlying uncertainties are high. Interestingly, risk considerations from specialization in a bank's industry portfolio are a less pressing issue for firms with opportunities to signal the value of their R&D activities through patents. Venture capital investments or government R&D subsidies are valuable for firms in themselves but provide no further signaling effect to a firm's main bank.

On the policy making side, our results cast doubts on a general call for banks specializing in financing innovation. Banks with a broad industry portfolio are equally valuable because they can manage risks through diversification especially for firms operating in more stable technological environments. What is more, we find that government R&D subsidies have value for firm R&D investment in itself but their effect as a signaling tool to banks should not be overestimated. A similar logic applies for the potential signaling from venture capital investors.

In sum, our research provides a novel perspective on the relationship between banks, their information availabilities and R&D investment of their firm. This provides fruitful avenues for future research. First, we develop and test strictly comparative arguments. This is partly due to the fact that the vast majority of the firms in our sample (85%) never changes their main bank. However, more detailed insights into how firms and banks select these relationships would be an important addition to our current model both theoretically and empirically. Secondly, we are able to investigate our research question empirically for a large economy with a well established, diverse financial system. However, European economies have been described as being especially reliant on bank financing. Comparative studies in Anglo-American settings could provide valuable insights into the international generalizability. Thirdly, we have focused on the R&D input side of the firm. Banks may not just influence overall R&D investment but also the nature of firm R&D as well as the outcomes. We suspect that this particular research question lends itself more to qualitative research but we are confident that our comprehensive, quantitative analyses provides a reliable base for it.

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TABLES

Table 1: Descriptive statistics

Variable	Level	Scale	Obs	Mean	Std. dev.
Share of R&D expenditure in total sales	Firm	ratio	7,294	0.03	0.09
Bank sector specialization	Bank	continuous	7,294	5.93	7.54
Bank industry market share	Bank	continuous	7,294	0.36	0.55
Savings and cooperative banks	Bank	dummy	7,294	0.50	0.50
Bank size (in logs)	Bank	continuous	7,294	10.33	1.28
Bank geogr. scope	Bank	percentage	7,294	66.59	34.74
No of banks	Firm	continuous	7,294	2.17	1.24
Switch of bank relation	Firm	dummy	7,294	0.15	0.36
Return on sales (t-1)	Firm	stand. index	7,294	-0.03	0.99
Patentstock per empl.	Firm	ratio	7,294	0.00	0.01
Company age since found. (years)	Firm	continuous	7,294	17.02	14.17
No of employees	Firm	continuous	7,294	144.82	323.19
Gov. R&D subsidy	Firm	dummy	7,294	0.16	0.36
Credit rating	Firm	stand. index	7,294	-0.02	0.86
Incorporated company on stocks	Firm	dummy	7,294	0.03	0.18
Venture capital investor	Firm	dummy	7,294	0.00	0.07
Part of company group	Firm	dummy	7,294	0.38	0.49
Location East Germany	Firm	dummy	7,294	0.37	0.48
Use of scientific knowledge	Industry	percentage	7,294	50.98	13.29
Medium-tech manuf.	Industry	dummy	7,294	0.29	0.45
High-tech manuf.	Industry	dummy	7,294	0.08	0.28
Low knowledge-intens. services	Industry	dummy	7,294	0.15	0.35
Knowledge-intens. services	Industry	dummy	7,294	0.29	0.45

Table 2: Estimation results of tobit models

Variable	Model 1	Model 2	Model 3
Bank sector specialization		-0.002***	-0.002***
		(0.00)	(0.00)
Bank industry market share		0.013***	0.013**
		(0.00)	(0.01)
Int: Bank spec. * market share			0.000
			(0.00)
Savings and cooperative banks	-0.023***	-0.026***	-0.026***
	(0.01)	(0.01)	(0.01)
Bank size (in logs)	0.001	-0.003	-0.003
	(0.00)	(0.00)	(0.00)
Bank geogr. scope	0.000	0.000	0.000
	(0.00)	(0.00)	(0.00)
Switch of bank relation	0.007	0.006	0.006
	(0.01)	(0.01)	(0.01)
No of banks	-0.002	-0.001	-0.001
	(0.00)	(0.00)	(0.00)
Use of scientific knowledge	0.002***	0.002***	0.002***
	(0.00)	(0.00)	(0.00)
Return on sales	-0.003*	-0.004*	-0.004*
	(0.00)	(0.00)	(0.00)
Patent stock per empl.	1.864***	1.853***	1.853***
	(0.27)	(0.27)	(0.27)
No of employees	0.004**	0.004**	0.004**
	(0.00)	(0.00)	(0.00)
Company age since found. (years)	-0.010***	-0.010***	-0.010***
	(0.00)	(0.00)	(0.00)
Gov. R&D subsidy	0.103***	0.103***	0.103***
	(0.00)	(0.00)	(0.00)
Credit rating	0.001	0.001	0.001
	(0.00)	(0.00)	(0.00)
Incorporated company on stocks	0.026**	0.023*	0.023*
	(0.01)	(0.01)	(0.01)
Venture capital investor	0.129***	0.123***	0.123***
	(0.02)	(0.02)	(0.02)
Part of company group	0.000	-0.001	-0.001
	(0.00)	(0.00)	(0.00)
Location East Germany	-0.004	-0.005	-0.005
	(0.01)	(0.01)	(0.01)
Medium-tech manuf.	-0.015	-0.013	-0.012
	(0.01)	(0.01)	(0.01)
High-tech manuf.	0.032***	0.032***	0.032***
	(0.01)	(0.01)	(0.01)
Low knowledge-intens. services	-0.068***	-0.062***	-0.062***
	(0.01)	(0.01)	(0.01)
Knowledge-intens. services	0.006	0.019**	0.019**
	(0.01)	(0.01)	(0.01)
Year 2004	-0.019***	-0.018***	-0.018***
	(0.01)	(0.01)	(0.01)
Year 2005	-0.001	-0.001	-0.001
	(0.00)	(0.00)	(0.00)
Year 2006	0.029***	0.029***	0.029***

Variable	Model 1	Model 2	Model 3
	(0.01)	(0.01)	(0.01)
Year 2007	-0.002	-0.002	-0.002
	(0.00)	(0.00)	(0.00)
Constant	-0.193***	-0.145***	-0.146***
	(0.03)	(0.03)	(0.03)
sigma_u	0.108***	0.107***	0.107***
	(0.00)	(0.00)	(0.00)
sigma_e	0.077***	0.077***	0.077***
	(0.00)	(0.00)	(0.00)
Observations	7294	7294	7294
Number of IDs	4363	4363	4363
LR Chi2	1249.870	1288.900	1289.000
log likelihood	698.790	716.960	716.980

* p<0.10, ** p<0.05, *** p<0.01

Table 3: Estimation results of tobit models with sub-samples of above/below average industry use of scientific knowledge

Variable	**Industry with below average science use**	**Industry with above average science use**
Bank sector specialization	-0.000*	-0.002***
	(0.00)	(0.00)
Bank industry market share	0.000	0.017***
	(0.00)	(0.01)
Savings and cooperative banks	0.000	-0.032***
	(0.00)	(0.01)
Bank size (ln)	0.000	-0.010
	(0.00)	(0.00)
Bank geogr. scope	0.000	0.000
	(0.00)	(0.00)
Switch of bank relation	0.007**	0.00
	(0.00)	(0.01)
No of banks	0.000	0.000
	(0.00)	(0.00)
Use of scientific knowledge	0.000	0.002***
	(0.00)	(0.00)
Return on sales	0.000	-0.006**
	(0.00)	(0.00)
Patent stock per empl.	0.871***	1.847***
	(0.32)	(0.32)
No of employees	0.003***	0.005*
	(0.00)	(0.00)
Company age since found. (years)	-0.003*	-0.010**
	(0.00)	(0.00)
Gov. R&D subsidy	0.046***	0.105***
	(0.00)	(0.01)
Credit rating	0.000	0.007*
	(0.00)	(0.00)
Incorporated company on stocks	-0.010	0.034**
	(0.01)	(0.02)
Venture capital investor	0.039**	0.138***
	(0.02)	(0.03)
Part of company group	0.000	-0.010
	(0.00)	(0.01)
Location East Germany	-0.006*	0.000
	(0.00)	(0.01)
Medium-tech manuf.	0.018***	-0.056***
	(0.00)	(0.01)
High-tech manuf.	omitted	-0.01
		(0.01)
Low knowledge-intens. services	-0.020***	-0.144***
	(0.00)	(0.02)
Knowledge-intens. services	-0.020***	omitted
	(0.00)	
Year 2004	-0.008**	-0.017**
	(0.00)	(0.01)
Year 2005	0.000	0.000
	(0.00)	(0.01)

Variable	**Industry with below average science use**	**Industry with above average science use**
Year 2006	0.007**	0.036***
	(0.00)	(0.01)
Year 2007	0.000	0.000
	(0.00)	(0.01)
Constant	-0.036**	-0.09
	(0.02)	(0.06)
sigma_u	0.040***	0.120***
	(0.00)	(0.00)
sigma_e	0.027***	0.086***
	(0.00)	(0.00)
Observations	3254	4040
Number of IDs	2033	2424
LR Chi2	315.48	658.32
log likelihood	660.56	595.31

* p<0.10, ** p<0.05, *** p<0.01

Table 4: Estimation results of tobit models including interaction effects

Variable	Model 4	Model 5	Model 6
Bank sector specialization	-0.002***	-0.002***	-0.002***
	(0.00)	(0.00)	(0.00)
Bank industry market share	0.012**	0.013***	0.013***
	(0.00)	(0.00)	(0.00)
Savings and cooperative banks	-0.025***	-0.026***	-0.026***
	(0.01)	(0.01)	(0.01)
Int: Patents * bank sector spec.	0.002**		
	(0.00)		
Int: Patents * bank market share	0.000		
	(0.01)		
Int: VC * bank sector spec.		-0.012	
		(0.01)	
Int: VC * bank market share		0.002	
		(0.07)	
Int: Gov. subs. * bank sector spec.			0.001
			(0.00)
Int: Gov. subs. * bank market share			-0.001
			(0.01)
Bank size (in logs)	-0.003	-0.003	-0.003
	(0.00)	(0.00)	(0.00)
Bank geogr. scope	0.000	0.000	0.000
	(0.00)	(0.00)	(0.00)
Switch of bank relation	0.006	0.007	0.007
	(0.01)	(0.01)	(0.01)
No of banks	-0.001	-0.001	-0.001
	(0.00)	(0.00)	(0.00)
Use of scientific knowledge	0.002***	0.002***	0.002***
	(0.00)	(0.00)	(0.00)
Return on sales	-0.004*	-0.003*	-0.004*
	(0.00)	(0.00)	(0.00)
Patent stock per empl.	1.677***	1.851***	1.861***
	(0.29)	(0.27)	(0.27)
No of employees	0.004**	0.004**	0.004**
	(0.00)	(0.00)	(0.00)
Company age since found. (years)	-0.010***	-0.010***	-0.010***
	(0.00)	(0.00)	(0.00)
Gov. R&D subsidy	0.103***	0.103***	0.099***
	(0.00)	(0.00)	(0.01)
Credit rating	0.001	0.001	0.001
	(0.00)	(0.00)	(0.00)
Incorporated company on stocks	0.022*	0.023**	0.023**
	(0.01)	(0.01)	(0.01)
Venture capital investor	0.123***	0.154***	0.123***
	(0.02)	(0.04)	(0.02)
Part of company group	-0.001	-0.001	-0.001
	(0.00)	(0.00)	(0.00)
Location East Germany	-0.005	-0.005	-0.005
	(0.01)	(0.01)	(0.01)
Medium-tech manuf.	-0.013	-0.012	-0.012
	(0.01)	(0.01)	(0.01)
High-tech manuf.	0.032***	0.032***	0.033***

Variable	Model 4	Model 5	Model 6
	(0.01)	(0.01)	(0.01)
Low knowledge-intens. services	-0.062***	-0.062***	-0.062***
	(0.01)	(0.01)	(0.01)
Knowledge-intens. services	0.019**	0.019**	0.020**
	(0.01)	(0.01)	(0.01)
Year 2004	-0.019***	-0.019***	-0.019***
	(0.01)	(0.01)	(0.01)
Year 2005	-0.001	-0.001	-0.001
	(0.00)	(0.00)	(0.00)
Year 2006	0.028***	0.029***	0.028***
	(0.01)	(0.01)	(0.01)
Year 2007	-0.002	-0.002	-0.002
	(0.00)	(0.00)	(0.00)
Constant	-0.147***	-0.145***	-0.144***
	(0.03)	(0.03)	(0.03)
sigma_u	0.107***	0.107***	0.107***
	(0.00)	(0.00)	(0.00)
sigma_e	0.077***	0.077***	0.077***
	(0.00)	(0.00)	(0.00)
Observations	7294	7294	7294
Number of IDs	4363	4363	4363
LR Chi2	1292.950	1292.080	1289.920
log likelihood	719.320	717.990	717.840

* p<0.10, ** p<0.05, *** p<0.01

APPENDIX

Appendix A: Construction of industry variables

Industry	NACE Code	Industry Group
Mining and quarrying	10 – 14	Low-tech manufacturing
Food and tobacco	15 – 16	Low-tech manufacturing
Textiles and leather	17 – 19	Low-tech manufacturing
Wood / paper / publishing	20 – 22	Low-tech manufacturing
Chemicals / petroleum	23 – 24	Medium high-tech manufacturing
Plastic / rubber	25	Low-tech manufacturing
Glass / ceramics	26	Low-tech manufacturing
Metal	27 – 28	Low-tech manufacturing
Manufacture of machinery and equipment	29	Medium tech manufacturing
Manufacture of electrical machinery	30 – 32	High-tech manufacturing
Medical, precision and optical instruments	33	High-tech manufacturing
Manufacture of motor vehicles	34 – 35	Medium tech manufacturing
Manufacture of furniture, jewellery, sports equipment and toys	36 – 37	Low-tech manufacturing
Electricity, gas and water supply	40 – 41	Low-tech manufacturing
Construction	45	Low-tech manufacturing
Retail and motor trade	50, 52	Low knowledge-intensive services
Wholesale trade	51	Low knowledge-intensive services
Transportation and communication	60 – 63, 64.1	Low knowledge-intensive services
Financial intermediation	65 – 67	Knowledge-intensive services
Real estate activities and renting	70 – 71	Distributive services
ICT services	72, 64.3	Knowledge-intensive services
Technical services	73, 74.2, 74.3	Knowledge-intensive services
Consulting	74.1, 74.4	Knowledge-intensive services
Low-tech business-oriented services	74.5 – 74.8, 90	Low knowledge-intensive services

Appendix B: Correlation matrix and variance inflation factors

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
(1)	R&D int.	1.00													
(2)	Bank sector specialization	-0.06	1.00												
(3)	Bank industry market share	0.03	0.13	1.00											
(4)	Savings and cooperative banks	-0.08	-0.08	-0.35	1.00										
(5)	Bank size (in logs)	0.05	-0.07	0.53	-0.45	1.00									
(6)	Bank geogr. scope	-0.04	0.00	-0.26	0.55	-0.34	1.00								
(7)	No of banks	0.02	-0.01	0.02	-0.01	0.00	-0.09	1.00							
(8)	Switch of bank relation	-0.09	0.01	0.07	-0.06	0.01	-0.02	-0.01	1.00						
(9)	Return on sales	0.20	-0.01	0.04	-0.14	0.04	-0.09	0.02	-0.01	1.00					
(10)	Patent stock per empl.	-0.04	-0.02	0.02	0.02	0.03	0.00	-0.01	-0.04	0.03	1.00				
(11)	Company age since found. (years)	0.15	-0.03	0.02	-0.03	0.03	-0.04	0.00	0.08	0.13	0.05	1.00			
(12)	No of employees	-0.08	0.03	0.21	-0.21	0.11	-0.14	0.02	0.40	0.02	-0.02	0.11	1.00		
(13)	Gov. R&D subsidy	-0.10	0.01	0.05	-0.05	0.02	-0.02	-0.05	0.29	-0.05	-0.01	0.02	0.14	1.00	
(14)	Credit rating	0.38	-0.06	0.02	-0.09	0.03	-0.06	0.01	-0.04	0.22	-0.01	0.13	0.05	-0.10	1.00
(15)	Incorporated company on stocks	0.04	0.02	-0.07	0.08	-0.04	0.06	-0.01	-0.17	-0.04	-0.10	-0.05	-0.26	-0.09	-0.02
(16)	Venture capital investor	0.06	-0.03	0.04	-0.02	0.05	-0.02	0.01	0.09	0.05	0.01	0.08	0.13	-0.13	0.08
(17)	Part of company group	0.09	-0.03	-0.01	-0.04	0.00	0.00	-0.02	0.03	0.01	-0.01	0.01	0.04	-0.01	0.05
(18)	Location East Germany	0.13	-0.09	0.13	-0.17	0.06	-0.10	0.02	0.21	0.25	0.07	0.24	0.31	0.06	0.17
(19)	Use of scientific Knowl.	-0.02	0.00	0.15	-0.18	0.09	-0.14	0.05	0.12	0.05	0.01	0.08	0.42	0.03	0.03
(20)	Medium-tech manuf.	0.11	-0.07	-0.08	-0.14	0.00	-0.12	0.04	-0.23	0.00	-0.05	-0.06	-0.16	-0.22	0.13
(21)	High-tech manuf.	-0.04	-0.13	-0.01	-0.09	-0.03	-0.07	0.01	0.15	0.47	0.01	0.08	0.20	0.06	0.07
(22)	Low Knowl.-intens. serv.	0.18	-0.14	0.06	-0.07	0.05	-0.05	0.00	0.01	0.30	0.07	0.13	0.05	-0.01	0.21
(23)	Knowl.-intens. serv.	-0.12	-0.01	-0.03	0.06	-0.03	0.03	0.01	0.01	-0.17	-0.06	-0.07	-0.04	0.04	-0.12
(24)	Knowl.-intens. serv.	0.13	0.33	0.00	-0.02	0.08	0.03	-0.01	-0.22	0.04	0.03	-0.05	-0.23	-0.14	0.01
(25)	Year 2004	0.00	0.01	-0.02	-0.01	-0.02	0.00	-0.01	0.01	0.01	-0.01	0.00	-0.01	-0.01	0.07
(26)	Year 2005	-0.02	-0.02	0.00	0.01	-0.01	0.00	-0.01	0.01	-0.02	0.01	-0.01	0.02	-0.03	0.02
(27)	Year 2006	-0.01	-0.02	0.00	0.00	0.01	-0.01	0.01	0.01	-0.01	0.00	0.02	0.01	0.04	-0.20
(28)	Year 2007	-0.01	-0.01	-0.01	0.03	0.00	-0.01	0.03	-0.02	0.01	0.00	0.01	-0.03	0.08	0.02
	VIF		1.27	1.56	1.80	1.70	1.50	1.02	1.37	2.54	1.04	1.09	1.67	1.19	1.21
(15)	Incorporated company on stocks	1.00													
(16)	Venture capital investor	-0.10	1.00												
(17)	Part of company group	-0.02	0.07	1.00											

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
(18)	Location East Germany	-0.11	0.08	0.07	1.00										
(19)	Use of scientific Knowl.	-0.13	0.07	0.04	0.21	1.00									
(20)	Medium-tech manuf.	0.07	-0.04	-0.01	-0.17	-0.10	1.00								
(21)	High-tech manuf.	-0.08	-0.02	0.00	0.30	0.08	-0.05	1.00							
(22)	Low Knowl.-intens. serv.	-0.02	0.07	0.02	0.23	0.04	0.00	-0.19	1.00						
(23)	Knowl.-intens. serv.	-0.02	-0.04	-0.02	-0.15	-0.02	-0.02	-0.26	-0.12	1.00					
(24)	Knowl.-intens. serv.	0.10	0.03	0.01	-0.26	-0.08	0.08	-0.40	-0.19	-0.26	1.00				
(25)	Year 2004	-0.03	0.01	-0.01	-0.02	0.04	0.02	0.00	-0.01	0.02	0.01	1.00			
(26)	Year 2005	0.01	0.00	-0.01	0.00	0.21	-0.04	0.00	-0.01	0.00	-0.01	-0.18	1.00		
(27)	Year 2006	-0.02	-0.01	0.00	0.03	-0.05	0.02	0.02	-0.01	-0.02	-0.03	-0.14	-0.27	1.00	
(28)	Year 2007	0.01	0.00	0.02	0.01	-0.12	-0.01	0.00	0.01	-0.01	-0.02	-0.20	-0.37	-0.29	1.00
	VIF	1.11	1.08	1.02	1.43	1.34	1.22	3.98	2.39	1.77	3.02	1.35	1.80	1.66	1.82

Appendix C: Consistency check estimation results

Variable	**Model 4** Full sample Regression	**Model 5** Sub sample Savings and cooperative banks	**Model 6** Sub sample Private and national banks	**Model 7** Sub sample Low tech industries	**Model 8** Sub sample High tech industries	**Model 9** Full sample IV 1st stage - Bank switch	**Model 10** Full sample IV 2nd stage
Bank sector specialization	-0.001***	-0.002***	-0.003***	0.000	-0.002***	0.000	-0.002***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Bank industry market share	0.006**	0.028**	0.001***	0.002	0.013**	0.014	0.011**
	(0.00)	(0.01)	(0.00)	(0.00)	(0.01)	(0.01)	(0.00)
Savings and cooperative banks	-0.010***			-0.004	-0.030***	0.043***	-0.030***
	(0.00)			(0.00)	(0.01)	(0.01)	(0.01)
Bank size (in logs)	-0.001	0.000	-0.009***	-0.001	-0.003	-0.008*	-0.003
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Bank geogr. scope	0.000	-0.000*	0.000**	0.000	0.000	-0.001***	0.000
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Switch of bank relation	0.004	0.008	0.005	0.010***	0.003		0.146
	(0.00)	(0.01)	(0.01)	(0.00)	(0.01)		(0.14)
No of banks	-0.001**	0.000	-0.002	0.000	-0.002	0.000	0.000
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Use of scientific knowledge	0.001***	0.002***	0.002***	0.000	0.003***	0.001	0.002***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Return on sales	-0.004***	-0.004	-0.004	0.001	-0.005**	-0.003	-0.004*
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Patent stock per empl.	1.332***	1.442***	2.028***	0.962***	1.885***	-0.180	1.945***
	(0.30)	(0.39)	(0.37)	(0.36)	(0.31)	(0.62)	(0.26)
No of employees	-0.004***	0.003	0.005**	0.003**	0.003	0.003	0.002
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Company age since found. (years)	-0.003**	-0.010**	-0.009**	-0.003*	-0.010***	-0.020***	-0.007*
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)

Variable	Model 4 Full sample Regression	Model 5 Sub sample Savings and cooperative banks	Model 6 Sub sample Private and national banks	Model 7 Sub sample Low tech industries	Model 8 Sub sample High tech industries	Model 9 Full sample IV 1st stage - Bank switch	Model 10 Full sample IV 2nd stage
Gov. R&D subsidy	0.077***	0.096***	0.104***	0.044***	0.108***	0.009	0.153***
	(0.01)	(0.01)	(0.01)	(0.00)	(0.01)	(0.01)	(0.01)
Credit rating	0.002	0.000	0.003	-0.001	0.004	-0.001	0.001
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)
Incorporated company on stocks	0.011	0.046***	0.001	-0.012	0.038***	-0.008	0.015
	(0.01)	(0.02)	(0.02)	(0.01)	(0.01)	(0.02)	(0.01)
Venture capital investor	0.083*	0.064	0.133***	0.033	0.135***	-0.094	0.125***
	(0.05)	(0.05)	(0.03)	(0.02)	(0.03)	(0.06)	(0.03)
Part of company group	-0.002	0.002	-0.004	0.004	-0.003	0.035***	0.002
	(0.00)	(0.01)	(0.01)	(0.00)	(0.01)	(0.01)	(0.01)
Location East Germany	0.004	-0.009	-0.001	-0.005	-0.005	0.027***	-0.013**
	(0.00)	(0.01)	(0.01)	(0.00)	(0.01)	(0.01)	(0.01)
Medium-tech manuf.	-0.015***	-0.007	-0.017			-0.015	-0.005
	(0.00)	(0.01)	(0.01)			(0.02)	(0.01)
High-tech manuf.	0.018***	0.027*	0.030*		0.043***	-0.025	0.042***
	(0.01)	(0.01)	(0.02)		(0.01)	(0.02)	(0.01)
Low knowledge-intens. services	-0.010***	-0.065***	-0.054***	-0.019***		0.008	-0.063***
	(0.00)	(0.01)	(0.01)	(0.00)		(0.02)	(0.01)
Knowledge-intens. services	0.019***	0.013	0.041***		0.032***	-0.003	0.024***
	(0.00)	(0.01)	(0.01)		(0.01)	(0.02)	(0.01)
Year 2004	-0.008***	-0.024***	-0.020***	-0.008	-0.019***	0.014	-0.022**
	(0.00)	(0.01)	(0.01)	(0.00)	(0.01)	(0.02)	(0.01)
Year 2005	-0.005*	0.002	-0.008	0.009**	-0.006	0.014	-0.005
	(0.00)	(0.01)	(0.01)	(0.00)	(0.01)	(0.01)	(0.01)
Year 2006	0.009***	0.023***	0.028***	0.011***	0.033***	0.042***	0.033***
	(0.00)	(0.01)	(0.01)	(0.00)	(0.01)	(0.01)	(0.01)
Year 2007	-0.003	-0.008	0.000	0.002	-0.003	0.050***	-0.005
	(0.00)	(0.01)	(0.01)	(0.00)	(0.01)	(0.01)	(0.01)
Bank branches in district (logs)						0.021***	
						(0.01)	
GDP in district						0.000	
						(0.00)	
Constant	0.017	-0.157***	-0.074*	-0.035*	-0.206***	0.174***	-0.161***
	(0.01)	(0.04)	(0.04)	(0.02)	(0.04)	(0.06)	(0.05)
sigma_u		0.099***	0.114***	0.040***	0.118***		
		(0.00)	(0.00)	(0.00)	(0.00)		
sigma_e		0.076***	0.073***	0.028***	0.083***		
		(0.00)	(0.00)	(0.00)	(0.00)		
Observations	7294	3676	3618	2503	4791	7294	7294
Number of IDs	4363	2262	2154	1571	2865	4363	4363
F-test/LR Chi2	22.94	555.83	731.25	188.84	795.30	5.83	1874.33
log likelihood	8286.92	181.69	584.38	444.40	618.66	-2704.13	21888.10

* p<0.10, ** p<0.05, *** p<0.01

[i] Important industry characteristics encompass the degree of competition in the product market requiring investments in new products and processes (e.g. Schumpeter, 1942; Aghion, Harris, Howitt & Vickers, 2001), technological and legal opportunities for appropriating returns (e.g. Teece, 1986) as well as providing technological opportunities (e.g. McGahan & Silverman, 2006). Existing knowledge stocks (e.g. patents or employee skills) allow the firm to benefit from complementarities in their current R&D investments (e.g. Cohen & Levinthal, 1989; Dierickx & Cool, 1989).