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Non-technical Summary

Research and development (R&D) activities of firms can be seen as investments in the creation of knowledge. This basic fact makes raising funds for investment in R&D projects different from capital investment. R&D investment is not only characterized by high, sunk, firm-specific investment cost and low collateral value, but also by significant adjustment cost. Further, the creation of positive externalities and uncertainty of returns affect financing conditions for such projects. Hence, firms' R&D activities may be pursued at a sub-optimal level or not conducted at all if financing becomes too expensive or is not available at all.

As investment in new knowledge is a crucial factor for the creation of wealth, from a society's point of view potential underinvestment is regarded as justification for government intervention to promote R&D investment. However, in order to design efficient support programs it is crucial to identify potentially constrained firms.

This study analyzes both R&D investment and capital investment based on firm-level panel data. Thereby, the effects of internal and external funding resources for both types of investment are compared. A positive reaction of changes in the firms' funding resources is interpreted as an indication of the firms being financially constrained in their investment. Moreover, the models distinguish effects for firms of different size and different age. This allows us to identify attributes affecting the level of constriction for both types of investment.

The results show that the availability of internal funds is more decisive for R&D investment than for capital investment. For both types of investment, we find a monotonic relationship between the impact of the constriction and firm size. The smaller the firms are, the more binding are financial constraints. Interestingly, capital investment reacts more sensitive to external constraints than R&D. We believe that this happens due to the fact that R&D is harder to finance through external resources in the first place. This is also reflected by the higher sensitivity of R&D to internal financial resources.

When looking at age differences, the relationship between the level of constriction and R&D investment is non-monotonic. For capital investment, we cannot identify differences between different age classes.

Das Wichtigste in Kürze (Summary in German)

Forschungs- und Entwicklungsaktivitäten (F&E) der Wirtschaft können als Investitionen die Schaffung neuen Wissens verstanden werden. Diese Perspektive verdeutlicht die fundamentalen Unterschiede zwischen F&E und anderen Formen von unternehmerischen Investitionen. F&E-Aktivitäten sind insbesondere gekennzeichnet durch hohe, versunkene, und oftmals firmenspezifische Kosten. Darüber hinaus enstehen meist nur geringe Anlagewerte, die als Sicherheiten bei der Finanzierung herangezogen werden können.

Die Entstehung positiver Externalitäten sowie Unsicherheit über den Erfolg der Investition können Finanzierungsbedingungen entscheidend beeinträchtigen. Zusätzlich sind F&E-Aufwendungen durch hohe Anpassungskosten charakterisiert. Dies kann dazu führen, dass privatwirtschaftliche Investitionen in F&E nur in reduziertem Umfang unternommen oder sogar unterlassen werden.

In wissensbasierten Volkswirtschaften stellen Investitionen in F&E jedoch einen der wichtigsten Faktoren für technologischen Fortschritt und wirtschaftliches Wachstum dar. Folglich werden potenziell unterlassene Investitionen häufig zur Rechtfertigung staatlicher Intervention zur Förderung von F&E-Aktivitäten in der Wirtschaft herangezogen. Für die effiziente Gestaltung solcher Programme ist es jedoch von großer Bedeutung solche Firmen zu identifizieren, die tatsächlich aufgrund von Finanzierungsengpässen geplante F&E-Projekte reduzieren oder sogar gänzlich unterlassen müssen.

Die nachfolgende Studie leistet einen Beitrag zu der Identifizierung von Unternehmen, die aufgrund mangelnder Finanzierungsmöglickeiten in der Durchführung von Investitionen in F&E eingeschränkt sind. Die Analyse basiert auf empirischen Modellen für F&E-Investitionen einerseits und Anlageinvestitionen andererseits. Dazu werden Panel-Daten deutscher Unternehmen verwendet. Der Einfluss interner und externer Finanzierungsquellen auf die Investitionsentscheidung steht dabei im Zentrum der Untersuchung.

Eine positive Reaktion der Investionen auf Veränderungen der Finanzierungsindikatoren kann als Hinweis auf eine hohe Sensibilität der Unternehmen auf die Verfügbarkeit von Finanzierungsmitteln interpretiert werden. Dies bedeutet, dass die Investitionsbereitschaft und –höhe nicht von vorhandenen Investitionsmöglichkeiten, sondern von der Verfügbarkeit von Finanzierungsquellen abhängt. Um firmenspezifische Attribute, die Existenz und Ausmaß der Finanzierungsengpässe beeinflussen, für die verschiedenen Investitionstypen identifizieren zu können, wird in den Modellen nach Unternehmensgröße und –alter differenziert.

Die Ergebnisse zeigen, dass interne Finanzierungsengpässe für Investitionen in F&E eine bedeutendere Rolle spielen als für Anlageinvestitionen. Darüber hinaus zeigt sich, dass F&E-Aufwendungen kleinerer Firmen mehr von externen Finanzierungsengpässen betroffen sind als es bei größeren Firmen der Fall ist. Dabei nimmt das Ausmaß der Finanzierungsengpässe monoton mit zunehmender Firmengröße ab.

Bei einer differenzierten Betrachtung nach Unternehmensalter, lässt sich keine monotone Beziehung zwischen Finanzierungsmöglichkeiten und Investitionshöhe finden.

R&D Investment and Financing Constraints of Small and Medium-Sized Firms*

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Abstract

This study tests for financial constraints on R&D investment and how they differ from capital investment. To identify constraints in the access to external capital, we employ a credit rating index. Our models show that internal constraints, measured by mark-ups, are more decisive for R&D than for capital investment. For external constraints, we find a monotonic relationship between the level of constriction and firm size for both types of investment. Thus, external constraints turn out to be more binding with decreasing firm size. On the contrary, we do not find such monotonic relationships for internal constraints. Differentiation by firms' age does not support lower constraints for older firms.

Keywords: R&D Investment, Capital Investment, Financial Constraints, Panel Data, Censored Regression Models

JEL-Classification: O31, O32

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1 Introduction

Innovations typically result from investment in research and development (R&D). From that perspective, R&D activities of firms can be seen as private investments in the creation of knowledge. This basic fact makes investment in R&D projects different from other types of investment.

Like any investment, however, R&D investment projects require financial resources. R&D investment in particular, is characterized by high, and usually firm specific investment cost, on the one hand, and low collateral value, on the other hand. Moreover, establishing an R&D program involves significant sunk costs and adjusting the level of R&D spending is costly because a major part of R&D spending consists of the wages of R&D employees. As these employees are usually high-skilled workers, hiring and training them is very costly and leads to low volatility in R&D spending over time (see Hall 2002 for a survey).

Information asymmetries between investors and managers additionally create uncertainty that affects financing conditions and hence may impede investment in R&D. This restriction, however, is not necessarily the same for all firms. Its extent may substantially depend on firm characteristics.

While a large part of private R&D investments is spent by large and established companies, the role of either young or small- and medium sized companies increasingly attracts scholars' and policy makers' attention. The contribution of these firms to technological progress through R&D and innovation has been found to be crucial (Acs and Audretsch 1990, Audretsch 2006).

However, given the characteristics of R&D investment, financing of such investment by external sources is expensive. Consequently, firms rely on internal sources of financing for their R&D projects to a great extent. This fact may constrain financing of R&D projects especially for firms whose internal financial sources are limited. Generally a firm is considered to be financially unconstrained if it can carry out all its R&D projects at optimal scale and constrained if it cannot due to insufficient financing.

Since the study of Fazzari et al. (1988), econometric studies have tried to detect financial constraints by comparing different groups of firms. On the one hand, supposedly unconstrained firms were identified and were expected to be able to raise funds for any investment. For those firms, R&D spending should not be sensitive to the availability of internal funds, which is usually measured by different kinds of cash flow indicators. On the other hand, the group of potentially constrained firms was expected to show a positive relationship between investment and the availability of financial resources, and thus be sensitive to the availability of internal funds. Classifications for grouping firms with respect to their investment sensitivity that are frequently used in the literature are firm size, financial market regimes and governance structures. However, there has been strong criticism in the literature whether the relationship between cash flow and investment is a sufficient indication of overall financial constraints (see Kaplan and Zingales, 1997, 2000, and the response by Fazzari et al., 2000). Moreover, the results concerning the existence of financial constraints are often ambiguous in these studies (see e.g. Harhoff 1998 and Bond et al. 2006, for discussions).

Because this discussion casts doubt on the cash flow approach, this study follows a different strategy of identifying financial constraints. We employ a credit-rating index to reflect financing opportunities of the rated firms more directly. As standardized credit ratings incorporate much more information about the firm than pure cash-flow measures, a sensitivity of investment to the rating index should represent a more reliable indicator of financing constraints. In addition, we derive an internal liquidity measure from the firms' empirical price-cost-margin.

Moreover, most previous studies focus on R&D performers, and thus neglect that a large share of smaller firms do not conduct R&D activities in the observed periods, possibly because of the lack of financial resources. Bond et al. (2006) attribute the weak results of many studies to the fact that 'financial constraints may manifest themselves more in the decision to set up R&D facilities, rather than in decisions about the year-to-year levels of spending in existing research programs.' Consequently, non-R&D performing firms and the endogeneity of their decision to invest in R&D are explicitly taken into account in this study.

We set up two empirical models. While we are mainly interested in financial constraints on R&D, we also compare the results to a capital investment model. We interpret a positive sensitivity of investment to internal resources as an indication of a restriction due to a lack of liquidity in the firm. Furthermore, a reaction of investment to changes in the firms' credit rating index serves as an indication for credit market restrictions. Moreover, our models allow distinguishing between differences in investment due to heterogeneity in firm size and age.

Our results show that indeed R&D investment differs from capital investment with respect to financing constraints and the importance of internal and external sources. First, the availability of internal funds is more decisive for R&D investments than for capital investment. Second, smaller firms suffer more from external constraints on R&D investment than larger firms.

For capital investment, we do not find this effect. This may be due to the lower impact of internal liquidity for capital investment so that external financing is the preferred, because less expensive, financing mode for all size classes. Further, we identify inter-group financing of R&D as being an alternative important source of funds, as the effects are considerably stronger for R&D than for capital investment.

When looking at age differences, however, no monotonic relationship between level of constriction and R&D-investment can be identified.

Section 2 gives an overview of insights in the literature on financial constraints on R&D investment. Section 3 presents the conceptual framework of this study and describes the data used for our analysis. In section 4, the econometric models and the results are described and section 5 provides robustness checks for our findings. Section 6 concludes.

2 Financing R&D

Firms fund their R&D projects either from internal sources, from external sources or from both. Unlike for capital investment, however, access to *external financing* for R&D investment may be more restrictive due to several reasons aggravating imperfections in capital markets. Information asymmetries about the value of the investment on the one hand, and the intangibility of the assets that are being created, on the other hand, affect financing conditions for R&D investment. Debtholders such as banks prefer physical and redeployable assets as security for their loans, since those can, at least partly, be liquidated in case the project fails or when the firms go bankrupt. Most R&D investments, however, are sunk and cannot be redeployed (Alderson and Betker 1996). Moreover, serving debt requires a stable cash flow. That may impede financing conditions for R&D through external sources, since most R&D projects do not immediately lead to results that can be commercialized (especially those involving basic research). In many cases it can take years of investing before the first return is realized (Hall 2002).

Studies also illustrate that raising new equity in order to finance R&D may be costly. For example Myers and Majluf (1984) argue that firms will also have to take into account a "Lemons Premium" when raising new equity if it can be raised at all. Moreover, empirical studies find a negative relationship between a firm's debt ratio and its R&D intensity. This may reflect the fact that those firms pursue less R&D activities because they have no access to new external funds and at the same time have to serve existing debt (Chung and Wright 1998, Czarnitzki and Kraft 2004).

Consequently, internal financing generally turns out to be the preferred option (or the only available option) for funding R&D investment. Internal funds may be less costly, but also limited. The potential problem for firms to finance R&D activities internally was first pointed out by Schumpeter (1934, 1939, 1942). He emphasized the necessity of temporary monopoly profit for financing of future R&D. Thereby arguing that (perfect) competition would not leave enough financial resources for R&D activities of firms in the long run. Thus, as pointed out by both Hall (1992) and Himmelberg and Petersen (1994), a positive cash flow may be more important for R&D than for other types of investment.

Based on the conclusion that firms mainly rely on internal funds as a consequence of imperfect capital markets, the empirical literature focused on detecting financing constraints due to lacking internal financing opportunities. This has been done by testing whether cash flow affects investment. The test is based on the idea that R&D expenditures will be determined by available cash flow if borrowing is constrained. Otherwise investment should not be sensitive to cash flow.

Empirical studies, however, do not always provide unambiguous results. Hall (1992), Himmelberg and Petersen (1994) and Harhoff (1998) find a positive relationship between R&D activity and cash flow for U.S. and German firms. Mulkey, Hall and Mairesse (2001) show that cash flow appears to be more important in the U.S. than in France for any type of investment. Bond et al. (2006) find for UK firms that cash flow determines whether a firm does R&D but not how much. They argue that this may indicate that R&D performing firms are a self-selected group of firms that are not constrained. However, they do not find such a relationship for Germany. Baghat and Welsh (1995) find a negative relationship between debt and R&D activity for U.S., but not for Japanese firms. For US and UK firms they observe a positive relationship between stock return and R&D activity two years later. Yet, they do not observe any relationship between cash flow and R&D. Bougheas et al. (2003) find similar results for Ireland.

Financing conditions for both internal and external sources may strongly depend on firms' characteristics. Small firms can benefit from advantages in implementing R&D projects, because their managers often know more about technology and exhibit entrepreneurial spirit and a positive attitude towards risk taking. In addition, R&D personnel in small firms may have more influence on decisions, and the number of owners is limited leading to more flexibility (Acs and Audretsch 1990, Czarnitzki and Kraft 2004).

While these aspects may positively impact financing opportunities for those firms, there are arguments illustrating that financing constraints due to asymmetric information between borrowers and lenders may be particularly binding for smaller firms. Small firms may have disadvantages because they cannot exploit scale economies and have less overall physical assets that could serve as collateral compared to large capital intensive companies.

Similarly, young firms may face different conditions than more established firms. First, young firms may be more financially constrained, because they cannot use earlier profit accumulations for financing their R&D projects. Older companies may not face that restriction. Moreover, older firms could benefit from their established bank contacts as banks use relationship lending to reduce problems of asymmetric information. Newly founded firms may not have built such relationships yet (Petersen and Rajan 1995, Martinelli 1997, Berger and Udell 2002). In addition, bank financing may be limited for R&D projects of young firms because of the higher default risk of young companies (Fritsch et al. 2006). This problem may become even more severe as the "Basle II Capital Accord" requires banks to conduct detailed risk assessment based on standardized rating systems. Czarnitzki and Kraft (2007) suggest that a rating in the third worst category (out of six) already results in three times higher interest rates than in the best category. Assuming that especially young firms a without track record and with uncertain prospects are rated rather low, bank loans would become too expensive for those firms. Since young companies can not rely on internal funds resulting from cash inflow from former product sales either, financing constraints may be more binding for such firms (Gompers and Lerner 1999, Ritter 1991).

Recent literature indeed provides evidence for the fact that young or small firms face financial constraints (Petersen and Rajan 1995, Berger and Udell 2002, Carpenter and Petersen 2002, Czarnitzki 2006). For older or larger companies evidence for constraints is harder to find. Moreover, established firms can innovate by building on their previous inventions, e.g. product variation or improvement, while younger firms may need to conduct more fundamental R&D which requires more resources and is much more uncertain.

In summary, the literature suggests that R&D investment may be subject to binding financial constraints. This may especially apply to small or young firms that may face higher cost of capital than larger or older firms. An empirical analysis to test for financial constraints in firm investment is presented in the following sections.

3 Conceptual Framework and data

This study advances previous work by taking into account and combining several aspects. We employ a credit-rating index to reflect financing opportunities of the rated firms more directly. This is should help to overcome the inaccuracies, arising from the measuring approaches in many earlier studies using cash flow as indicator for financial constraints.

Kaplan and Zingales (2000) argue that cash-flow sensitivity is not an appropriate measure for financial constraints as high cash flow sensitivities to R&D investment of firms cannot be interpreted as evidence for those firms being more financially constraint than firms with smaller sensitivities. They illustrate that with the example of Microsoft, which has a high sensitivity to investment and a very high overall liquidity at the same time, making severe constraints very unlikely. Thus, they criticize that the cash flow- investment sensitivity approach cannot distinguish between a) firms with more cash holding because they are highly profitable, b) firms with high cash flow because they follow for example a non-dividend strategy, c) firms with a low cash flow in order to reduce managerial cash disposal or d) firms with a low cash flow because they are simply less profitable. Thus, a high sensitivity cannot be interpreted as financial constraint because it could also be the case that firms use their high liquidity to invest. Thus, sensitivity could even be stronger for especially solvent firms und lower for firms with low cash flow levels. Further, firms with free cash flow under a certain threshold may even exhibit the lowest sensitivities as they do not start to invest even if cash flow increases.

Fazzari et al. (2000) defend their approach and point out limitations of the argumentation of Kaplan and Zingales (1997), but the usefulness of the cash flow approach remains highly controversial. When criticizing cash-flow measures, Kaplan and Zingales adopt the methodology of a case by case manual (credit) rating of firms that provids a more sophisticated indicator for long term liquidity.

The advantage of the credit rating indicator used in this article is that it is a standardized measure provided by Creditreform, Germany’s largest credit rating agency. Thus, it is in fact the actual rating that potential lenders would use to assess the creditworthiness of the firms in our sample.

In addition to the rating scores, we derive an internal liquidity measure from the firms' empirical price-cost margin. While we do not use this to identify credit market constraints as done in earlier studies, we still want to control for the availability of internal resources. The fact that the sample also includes non-R&D-performers allows taking the endogeneity of their decision to invest in R&D explicitly into account.

Further, we can compare R&D to capital investment for the same sample of firms. Previous studies such as Audretsch and Elston (2002) analyze the impact of liquidity constraints in capital investment on a sample of German firms. Their study is motivated by the idea that the special nature of the banking dominated financial system in Germany may alleviate or even avoid financial constraints. Their results show that this may not be the case for all firms. Firms in the smallest group in their sample seem to benefit from the institutional structure. For medium sized firms, however, the most severe liquidity constraints can be found, while for the largest firms in the sample no evidence of binding financial constraints on capital investment can be found. Thus, their results suggest a non-monotonic relationship between firm size and liquidity constraints for capital investment. However, it should be noted that Audretsch and Elston analyze a sample of rather large, stock market listed firms and therefore cannot generalize their findings to non-listed firms.

As the gap in financing due to imperfect capital markets may be especially severe when it comes to financing of R&D, we are interested in analyzing both financial constraints on capital investment and on R&D investment. Further, we aim to avoid a bias towards large firms by using a sample of firms that is more representative of the economy.

Finally, our models allow distinguishing between differences in investment due to heterogeneity in firm size and age.

The data used for the analysis stems from the Mannheim Innovation Panel (MIP) that provides us with firm-level survey data on the German business sector. The survey is conducted annually by the Centre for European Economic Research (ZEW), Mannheim. The survey identifies process and product innovators as well as non-innovative firms in manufacturing and service industries. Our study uses the survey from the manufacturing sector and our sample covers the years 1992 to 2002.1

Our sample is more representative of the economy than those used in several earlier studies, where scholars had to restrict their analysis to large firms or R&D-performing due to limitations in data availability.

Due to a large fraction of small firms (median size = 140 employees; a quarter of firms is smaller than 44 employees), firms may not conduct R&D in every year. We take this censoring of the dependent variable into account by estimating censored regression models (Tobit).

Taking the skewness of the distribution into account, we employ logarithms, ln(1+*R&D*), as dependent variable in our R&D investment model.2 As we are also interested in the differences in patterns for constraints between capital investment and R&D investment, we also run our models for capital investment (*INV*). As the distribution of capital investment is also skewed, we use the logarithm, that is *ln(1+INV),* here as well.

Since we want to identify financial constraints on R&D investment and capital investment in our models, the most important right-hand side variables are our indicators for the availability of funds. On the one hand, we include the credit rating index measuring access to external capital. We observe the level of constriction directly through the credit rating, which is a continuous measure (*RATING*). The credit rating is an index between 1 and 6, whereby an index of 6 represents the best rating[3].

We also construct additional variables that allow to model heterogeneous effects of the rating index for firms of different size classes. For this purpose, we interact *RATING* with 4 dummy variables (0 = does not belong to this size class, 1 = belongs to this size class) that attribute each firm to one of 4 size classes. Thereby, each of the four size classes contains 25% of the firms in the sample. This leads to 4 interaction-terms:

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[1] The questionnaire changes every year, and unfortunately the years 1999 and 2000 cannot be used in this study as relevant variables were not part of the survey in these years.
[2] R&D expenditure and capital investment are measured in million "Deutsche Mark" (1 DM ≈ 0.51 EUR).
[3] It should be noted that we use an inverted version of the original rating index for easier interpretation of the estimated effects. The original index ranges from 100 to 600, where 600 represents the worst rating. We simply switch it around so that higher values of the regressor stand for an improved rating. Further, we divided the rating by 100 in the regression models.

$$RATING_{i,t-1} \times SIZE\_CLASS\_X \qquad \text{with } X = 1,...,4 .$$

Because, we are not only interested in differences between firms of different size, but also in differences between firms of different age, we construct such interaction terms for equally sized *AGE*-classes analogous:

$$RATING_{i,t-1} \times AGE\_CLASS\_X \qquad \text{with } X = 1,...,4 .$$

Kaplan and Zingales (2000) argue that the practice of splitting the sample according to a measure of financial constraints and then comparing the sensitivities across groups only justified if investment sensitivities increase monotonically in the degree of financial constraints. Adding the 4 interaction terms to our models, allows us to test whether we indeed find such a monotonic relationship.

In order to test for monotonicity for our internal liquidity measure *PCM*, we also construct

$$PCM_{i,t-1} \times SIZE\_CLASS\_X \qquad \text{with } X = 1,...,4 .$$

Although we do not identify constraints through investment-cash flow relationships solely, we still want to control for the availability of internal funds. For the measurement of internal resources, scholars typically use cash-flow. As our data is based on a survey and is not limited to large firms which are obliged to publish balance sheet information, we do not observe cash-flow for our sample. Instead, we calculate an approximation for the availability of internal funds, the empirical price-cost margin (*PCM*) as

$$PCM_{it} = \frac{(\text{Sales}_{it} \text{ - Staff Cost}_{it} \text{ - Material Cost}_{it} + \delta \cdot \text{R\&D}_{it})}{\text{Sales}_{it}} .$$

This approach has been widely used in the literature (see Collins and Preston 1969, Ravenscraft 1983 for the seminal papers). Since R&D is an expense, the decision to invest in R&D will decrease *PCM* in the corresponding period. As we want to measure internally available funds during the year irrespective of the actual investment decision, it is common to add the R&D expenses back into *PCM* (cf. Harhoff 1998). As *PCM* does not account for capital cost, we only add the staff and material cost shares of R&D. These amount to 93% ($\delta = 0.93$) according to the Wissenschaftsstatistik (1999) which is the official German R&D statistic.

Further control variables are firm size measured by the value of fixed assets ln(*SIZE*) and its squared value $\ln(SIZE)^2$. We include this capital-related size measure, instead of using the total number of employees, for example, as capital may serve as collateral in credit negotiations with potential lenders, facilitating access to external sources of financing. We also use firms' age ln(*AGE*) to control for age-related effects. For instance, younger firms may conduct more R&D ceteris paribus than older firms as those could have more established products in the market. As we consider intra-group flows of resources as important option for funding investment projects, we include a dummy variable (*GROUP*) that is equal to one, if a firm is part of a group, and takes the value of zero otherwise.

We take business cycle effects into account by including a set of 8 time dummies (t) and we control for variation of R&D intensity across sectors by adding 10 industry dummies (*IND*) to our models. In order to avoid direct simultaneity between investment and the explanatory variables, we use lagged values of all time variant variables (except *AGE*).

Descriptive statistics are presented in Table 1. Average R&D expenditure *(R&D)* over all firms and years in the full sample is about 8 million DM (4.1 million €). In the sample of innovators only, that we use for our robustness checks, average R&D expenditure is naturally, although only slightly, higher. The same pattern applies to average capital investment *(INV)* that is with about 11 million DM and about 12 million DM higher for both samples, respectively. Average firm size *(SIZE)* measured in fixed assets is also considerably higher in the sample that excludes non-innovating firms. Average age is about 49 years in the full samples and about 50 years in the restricted sample. Interestingly, the average credit rating is only slightly higher among the innovators compared to the full sample.

Table 1: Descriptive Statistics

Variable	**Unit**	**Full Sample** (5,070 obs.)				**Innovators only** (4,037 obs.)			
		Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max
$R\&D_{it}$	R&D expenditure in million DM	8.056	74.088	0	2,030.612	8.606	76.898	0	2,030.612
INV_{it}	investment in million DM	11.070	100.203	0	3965	12.302	110.390	0	3965
$INNOEXP_{it}$	innovation expend. in million DM*	11.906	115.211	0	3719	13.672	126.914	0	3,719
$SIZE_{i,t-1}$	Fixed assets in thousand DM	46.450	235.415	0	5,255.084	49.262	234.556	0	5,255.084
AGE_{it}	Years elapsed since founding	48.561	41.050	1	198	49.878	41.742	1	198
$PCM_{i,t-1}$	Empirical price cost margin	0.272	0.152	-0.470	0.825	0.274	0.149	-0.470	0.825
$RATING_{it-1}/100$	Credit rating index; 1 = worst rating	5.010	0.550	1	6	5.047	0.538	1	6
GROUP	dummy for firms that are part of a group	0.359	0.480	0	1	0.416	0.493	0	1

Note: time and industry dummies omitted. *Used as an alternative limited dependent variable in the robustness checks. The number of observation for this variable is limited to 4,572 (full sample) and 3,615 (innovators only).

4 Econometric Models and Results

We estimate two different econometric models. First, we follow a pooled cross-sectional approach and second, we employ a random effects estimator to our panel data. The investment models to be estimated can be written as

$$I_{it} = \max\left(0, x_{it}^{'}\beta + c_i + u_{it}\right), \quad i = 1,2,\ldots,N, \quad t = 1,2,\ldots,T$$
$$u_{it} \mid x_i, c_i \sim N\left(0, \sigma_u^2\right)$$

where I_{it} is the dependent variable (both denoted as *I* being the natural logarithm of *INV* and *R&D,* respectively), x_{it} denotes the set of regressors, β the parameters to be estimated, and c_i the unobserved firm-specific effect, and u_{it} is the error term. We estimate two versions of this model. First, we assume that $c_i = 0$. Hence, the model can be estimated as a simple pooled cross-sectional model, where we adjust the standard errors for firm clusters to account for the panel structure of the data. Thus, we allow the error terms to be correlated within firm observations. The pooled model has the advantage that it is not necessary to maintain the strict exogeneity assumption. While u_{it} certainly has to be independent of x_{it}, the relationship between u_{it} and x_{is}, $t \neq s$, is not specified (see Wooldridge, 2002: 538). Hence, the model allows for feedback of R&D in period *t* to the regressors in future periods, for instance. In the second version of the model, we apply a random-effects Tobit panel estimator so that $c_i \neq 0$. However, this requires the strict exogeneity assumption. In addition, the random-effects Tobit requires the assumption that c_i is uncorrelated with x_{it}.

The basic model is specified as:

$$I_{it}^{*} = \beta_0 + \beta_1 RATING_{it-1} + \beta_2 PCM_{it-1} + \beta_3 \ln SIZE_{it-1} + \beta_4 \left(\ln SIZE\right)_{it-1}^{2} + \beta_5 \ln (AGE)_{it}$$
$$+ \beta_6 GROUP_{it} + \sum_{k=7}^{17} \beta_k IND_{ik} + \sum_{s=18}^{26} \beta_s t_s + c_i + u_{it}$$

and

$$I_{it} = \begin{cases} I_{it}^{*} & \text{if } \sum_{j=0}^{26} x_{jit-1}\beta_j + c_i + u_{it} > 0 \\ 0 & \text{otherwise} \end{cases}$$

After estimating the baseline models, we allow that the effects of the rating vary with firm size. There we estimate four separate slope coefficients of the rating variable for each size class through our interaction terms of the rating with firm size. Similarly, we proceed with the age interactions subsequently. We are interested whether we find a monotonic relationship between the rating and the size or age class, so that the investment constraints become more binding for either smaller or younger firms.

The results of both our baseline models and the extended specifications including the interaction terms of *RATING* with firm size classes are presented in Table 2. The first two columns present the results from the pooled cross-sectional model. For both, R&D investment and capital investment, *SIZE* and its squared term are highly significant. As both coefficients are positive, we find that the estimated coefficients describe a u-shaped curve, where the data, however, only cover the right branch of the parable. Thus the investment level is monotonically increasing with firm size. Being part of a group also turns out to positively impact both types of investment. Interestingly, this effect is considerably higher for R&D investment. This points to the conclusion that firms that are associated with a group have access to additional capital through their parent companies. This seems to be important for R&D, as firms may well be constrained by their own internal resources and their access to the credit market. *AGE* has also a significant, positive effect on R&D-investment, but not on capital investment. Note that we also experimented with non-linear age effects, but unlike the case of firm size, these never turned out to be significant.

Our measures for availability of financing (*PCM, RATING*) are highly positively significant for both types of investment, naturally indicating that both a higher price-cost margin and a better rating support higher firm investments. Yet, the results show differences between R&D and capital investment. The coefficient of *PCM,* reflecting the importance of internal sources of financing, is much higher for R&D investment than it is for capital investments. Accordingly, the impact of the indicator of availability of external funds is smaller for R&D investment compared to general investment.

The estimated coefficients describe the marginal effects of the regressors on the investment propensity *I**, such that (see e.g. Greene, 2000: 908-910).

$$\frac{\partial E\left[I_i^* \middle| x_i'\right]}{\partial x_{ik}} = \beta_k .$$

Table 2: Tobit regressions on ln(1+*R&D*) and ln(1+*INV*) and *RATING*SIZE_CLASS* interactions (5,070 obs.)

Variable	Pooled Cross Section Model		Pooled Cross Section Model - *RATING*SIZE* classes -		Random-Effects Panel Model - *RATING*SIZE* classes --	
	ln(R&D)$_{it}$	**ln(INV)$_{it}$**	**ln(R&D)$_{it}$**	**ln(INV)$_{it}$**	**ln(R&D)$_{it}$**	**ln(INV)$_{it}$**
ln(SIZE $_{i,t-1}$)	0.194 ***	0.224 ***	0.276 ***	0.289***	0.180***	0.252***
	(0.021)	(0.010)	(0.028)	(0.016)	(0.020)	(0.013)
ln(SIZE $_{i,t-1}$)^2	0.050 ***	0.054 ***	0.052 ***	0.051***	0.033***	0.043***
	(0.006)	(0.003)	(0.006)	(0.004)	(0.003)	(0.002)
ln(AGE) $_{it}$	0.072 **	0.007	0.078 **	0.011	0.119***	0.065***
	(0.033)	(0.017)	(0.033)	(0.017)	(0.027)	(0.018)
GROUP$_{it}$	0.317 ***	0.178 ***	0.340 ***	0.191***	0.158***	0.134***
	(0.057)	(0.035)	(0.057)	(0.035)	(0.035)	(0.026)
PCM $_{i,t-1}$	**1.011** ***	**0.336** ***	**1.013** ***	**0.340*****	**0.351*****	**0.147****
	(0.158)	(0.092)	(0.156)	(0.092)	(0.094)	(0.067)
RATING $_{i,t-1}$/100	**0.147** ***	**0.181** ***				
	(0.057)	(0.031)				
RATING $_{i,t-1}$*SIZE_CLASS_1			**0.197** ***	**0.219*****	**0.122*****	**0.183*****
			(0.062)	(0.033)	(0.034)	(0.024)
RATING $_{i,t-1}$*SIZE_CLASS_2			**0.172** ***	**0.176*****	**0.115*****	**0.136*****
			(0.061)	(0.033)	(0.033)	(0.023)
RATING $_{i,t-1}$*SIZE_CLASS_3			**0.125** **	**0.152*****	**0.085****	**0.111*****
			(0.060)	(0.032)	(0.033)	(0.023)
RATING $_{i,t-1}$*SIZE_CLASS_4			**0.088**	**0.150*****	**0.074****	**0.085*****
			(0.062)	(0.034)	(0.033)	(0.024)
Test of joint significance of time dummies	$\chi^2(8)$ = 89.96***	$\chi^2(8)$ = 16.26*	$\chi^2(8)$ = 89.07***	$\chi^2(8)$ = 24.71***	$\chi^2(8)$ = 89.69***	$\chi^2(8)$ = 25.14***
Test of joint significance of industry dummies	$\chi^2(10)$ = 308.68***	$\chi^2(10)$ = 23.71***	$\chi^2(10)$ = 305.70***	$\chi^2(10)$ = 16.45*	$\chi^2(10)$ = 360.80***	$\chi^2(10)$ = 27.76**
Test of difference of RATING*SIZE interactions			$\chi^2(3)$ = 12.35***	$\chi^2(3)$ = 24.97***	$\chi^2(3)$ = 11.94***	$\chi^2(3)$ = 58.36***
Log-Likelihood	-5,090.83	-5,451.16	-5,074.12	-5,428.84	-4,071.32	-4,839.11
ρ	-	-	-	-	0.724	0.518
# censored observations	2,414	309	2,414	309	2,414	309

Notes: All models include an intercept (not presented). Standard errors in parentheses (clustered in pooled cross-sectional models).
*** (**, *) indicate a significance level of 1% (5, 10%). ρ indicates the share of the total variance which is due to the cross-sectional variation.

Since our dependent variable is specified in logarithms, a unit change in our main variables of interest, i.e. *PCM* and *RATING*, can be interpreted as a percentage change in investment. For instance, if the price-cost margin changes from 10% to 20%, R&D investment (in terms of the latent index I^*) changes by 10%, all else constant, and capital investment only changes by about 3%. If the rating changes by 1 unit in our regression, R&D would change by 15% and capital investment by 18%.

Note that we could also compute the marginal effect on I instead of I^* as

$$\frac{\partial E\left[I_i \left| x_i^{'}\right.\right]}{\partial x_{ik}} = \beta_k \cdot \Phi\left(\frac{x_i^{'}\beta}{\sigma}\right).$$

In this case, R&D would change by 5% in response to a 10% change in PCM and by 7% if the rating changes by 1 unit, on average. Capital investment would increase by 2.6% in response to a 10% increase of PCM, and by 14% for a unit change in the rating.

The more interesting conclusion with respect to firm size, however, can be drawn from the regressions with interaction terms. First, we find that the estimated coefficients are not only significantly different from zero, but that they also differ from each other (see chi-squared tests at bottom of Table 2). In terms of marginal impact on I^*, a unit change in the rating causes the smallest firms to adjust R&D by about 20%. However, the effect monotonically decreases with increasing firm size from 20%, to 17%, 13% and 9% (last coefficient not significant), respectively in pooled cross-sectional model. In the panel model, the marginal effects are somewhat smaller but still monotonically decreasing and significantly different from zero as well as significantly different from each other. Again, the marginal effects on the capital investment propensity are larger than those for R&D.

As we observe from our first models that firms have to rely more on internal financing for R&D than for capital investment, we are also interested in testing for monotonicity in the relationship between investment and the interaction of firm size and *PCM*. This resembles, to a certain extent, the earlier studies on investment-cash flow relationships, where scholars tried to identify financial constraints purely by investment-cash flow sensitivities. There, financial constraints were interpreted as being present if a group of firms did not show any sensitivity (insignificant coefficient) but another group (e.g. smaller firms) did. We, however, supplement this approach by our credit rating, and thus, one should not expect to find a monotonic relationship (see also the Kaplan-Zingales critique mentioned earlier).

Table 3 presents the results from the extended models. The estimates on the firm level controls remain similar to the previous specification. While the effects for the *RATING*SIZE* interactions also remain robust (compare to Table 2), the coefficients of the *PCM*SIZE* interaction terms are not monotonically decreasing. Furthermore, the test on differences between the PCM coefficients reveals that they are not significantly different from each other. Thus, all models collapse to the ones shown in Table 2.

Age effects

While we already controlled for firm age in the previous models, we are still interested if firms' age and size have comparable effects on the access to external funding. For this, we include $RATING_{i,t-1} \cdot AGE\_CLASS\_X$ interactions rather than interactions with size classes. Interestingly, age seems to have a less clear effect on credit availability. We do neither find a monotonic relationship for R&D nor for capital investment. Therefore, we believe that access to external funding is more related to size arguments, especially such as collateral for additional loans, rather than to age argumentations, such as missing track histories or lending relationships with banks or suppliers. The detailed regression results are relegated to the appendix (see Table A.1).

Table 3: Tobit regressions on ln(1+*R&D*) and ln(1+*INV*) and *RATING**SIZE_CLASS* and *PCM*SIZE_CLASS* interactions (5,070 obs.)

Variable	Pooled Cross Section Model - *RATING*SIZE* classes -		Random-Effects Panel Model - *RATING*SIZE* classes -	
	$\ln(R\&D)_{it}$	**$\ln(INV)_{it}$**	**$\ln(R\&D)_{it}$**	**$\ln(INV)_{it}$**
$ln(SIZE_{i,t-1})$	0.276 ***	0.289***	0.182***	0.253***
	(0.028)	(0.017)	(0.020)	(0.013)
$ln(SIZE_{i,t-1})^2$	0.052 ***	0.051***	0.033***	0.043***
	(0.006)	(0.004)	(0.003)	(0.002)
$ln(AGE)_{it}$	0.079 **	0.012	0.119***	0.066***
	(0.033)	(0.017)	(0.027)	(0.018)
$GROUP_{it}$	0.342 ***	0.192***	0.159***	0.134***
	(0.057)	(0.035)	(0.035)	(0.026)
$PCM_{i,t-1}$*SIZE_CLASS_1	**0.861** ***	**0.226****	**0.086**	**0.115**
	(0.262)	(0.104)	(0.204)	(0.027)
$PCM_{i,t-1}$*SIZE_CLASS_2	**1.193** ***	**0.375****	**0.514*****	**0.266****
	(0.247)	(0.165)	(0.178)	(0.120)
$PCM_{i,t-1}$*SIZE_CLASS_3	**1.199** ***	**0.451****	**0.476*****	**0.193**
	(0.305)	(0.191)	(0.173)	(0.132)
$PCM_{i,t-1}$*SIZE_CLASS_4	**0.822** ***	**0.322*****	**0.301****	**0.021**
	(0.300)	(0.216)	(0.148)	(0.121)
$RATING_{i,t-1}$*SIZE_CLASS_1	**0.206** ***	**0.225*****	**0.139*****	**0.185*****
	(0.064)	(0.034)	(0.035)	(0.024)
$RATING_{i,t-1}$*SIZE_CLASS_2	**0.162** ***	**0.174*****	**0.107*****	**0.129*****
	(0.062)	(0.034)	(0.034)	(0.024)
$RATING_{i,t-1}$*SIZE_CLASS_3	**0.115** **	**0.146*****	**0.078****	**0.108*****
	(0.060)	(0.033)	(0.033)	(0.024)
$RATING_{i,t-1}$*SIZE_CLASS_4	**0.098**	**0.150*****	**0.077****	**0.091*****
	(0.063)	(0.036)	(0.034)	(0.025)
Test of joint significance of time dummies	$\chi^2(8)$ = 89.40***	$\chi^2(8)$ = 24.86***	$\chi^2(8)$ = 90.45***	$\chi^2(8)$ = 25.27***
Test of joint significance of industry dummies	$\chi^2(10)$ = 306.42***	$\chi^2(10)$ = 16.43*	$\chi^2(10)$ = 370.60***	$\chi^2(10)$ = 27.82**
Test of difference of *PCM*SIZE* interactions	$\chi^2(3)$ = 1.84	$\chi^2(3)$ = 1.37	$\chi^2(3)$ = 3.37	$\chi^2(3)$ = 2.41
Test of difference of *RATING*SIZE* interactions	$\chi^2(3)$ = 9.67**	$\chi^2(3)$ = 23.16***	$\chi^2(3)$ = 9.77**	$\chi^2(3)$ = 38.29***
Log-Likelihood	-5,072.78	-5,428.11	-4,069.09	-4,837.81
ρ			0.724	0.516
# censored observations	2,414	309	2,414	309

Notes: All models include an intercept (not presented). Standard errors in parentheses (clustered in pooled cross-sectional models).
*** (**, *) indicate a significance level of 1% (5, 10%). ρ indicates the share of the total variance which is due to the cross-sectional variation.

5 Robustness checks

As a robustness test of our results, we provide two different checks. First, we estimate the same model specifications as described in section 4 for a sub-sample of firms that have been innovators in at least two-periods in our overall sample period. This serves as a method to test whether differences between our capital investment model and the R&D investment model are due to the fact that we have firms in the sample that never performed any innovation activity. As can be seen in Table 4, all previous results obtained with the full sample are confirmed. This also applies to the rating-size interactions. Again, we relegate the regressions for the age effects to the appendix (see Table A.2), as the results do not improve for the subsample of innovating firms.

As a second robustness check, we test how sensitive our results are to changes in the definition of investments for innovation. Since R&D is only one component of successfully introducing new processes or new products to the market, it is interesting to check whether the results persist when one considers a broader measure of innovation activity. The database offers the opportunity to look at total innovation expenditure rather than R&D only. In addition to pure internal R&D, innovation expenditure comprises outsourcing of R&D, the acquisition of new (lab) equipment that is linked to an innovation project, the purchase of other intellectual property (e.g. patents or licenses), education expenditure which become necessary for training employees when implementing new technologies, market introduction cost that arise due to a product innovation, as well as design and prototyping and related activities.

The results are presented in Table 5. Note that our sample is slightly smaller than for the R&D regressions due to some missing values in the total innovation expenditure. So, we also reproduce the capital investment regressions for this sample in order to have an accurate comparison. These results add some interesting insights as a supplement to the R&D regressions. While the basic results are similar to the findings with R&D, the marginal impact of the RATING*SIZE interactions changes somewhat. We still find a monotonic relationship, but the magnitudes of the external constraints gets closer to those estimated for capital investment. As argued in the literature, adjusting R&D is more costly than capital investment, which implies that the firms try to smooth R&D spending over time. Thus, the observed reaction of R&D to financial constraints, as reported in Table 2, is lower than for capital investment. However, when looking at total innovation expenditure (Table 5), the effects become more similar to capital investments. This is possibly due to the fact that total innovation expenditure comprise some types of investment that show lower outcome uncertainty or that have more collateral value (e.g. buying a patent or license). For completeness, we also report the results from the age interaction variables in the appendix (see Table 3). However, the results remain inconclusive and are thus not discussed in more detail.

Table 4: Tobit regressions on ln(1+*R&D*) and ln(1+*INV*) and *RATING*SIZE_CLASS* interactions for innovators only (4,037 obs.)

	Pooled Cross Section Model		**Pooled Cross Section Model - *RATING*SIZE* classes -**		**Random-Effects Panel Model - *RATING*SIZE* classes --**	
Variable	**ln(R&D) $_{it}$**	**ln(INV) $_{it}$**	**ln(R&D) $_{it}$**	**ln(INV) $_{it}$**	**ln(R&D) $_{it}$**	**ln(INV) $_{it}$**
ln(SIZE $_{i,t-1}$)	0.155 ***	0.216 ***	0.232 ***	0.281***	0.160***	0.250***
	(0.023)	(0.012)	(0.029)	(0.019)	(0.021)	(0.015)
ln(SIZE $_{i,t-1}$)^2	0.051 ***	0.055 ***	0.053 ***	0.052***	0.034***	0.042***
	(0.006)	(0.004)	(0.007)	(0.005)	(0.004)	(0.003)
ln(AGE $_{it}$)	0.068 **	0.010	0.072 **	0.014	0.108***	0.076***
	(0.034)	(0.019)	(0.034)	(0.020)	(0.030)	(0.020)
GROUP$_{it}$	0.299 ***	0.191 ***	0.316 ***	0.201***	0.169***	0.166***
	(0.060)	(0.039)	(0.060)	(0.039)	(0.040)	(0.030)
PCM $_{i,t-1}$	**0.920** ***	**0.309** ***	**0.914** ***	**0.297*****	**0.304*****	**0.099**
	(0.174)	(0.110)	(0.172)	(0.109)	(0.102)	(0.078)
RATING $_{i,t-1}$/100	**0.134** **	**0.206** ***				
	(0.059)	(0.036)				
RATING $_{i,t-1}$*SIZE_CLASS_1			**0.182** ***	**0.250*****	**0.103****	**0.205*****
			(0.063)	(0.039)	(0.037)	(0.028)
RATING $_{i,t-1}$*SIZE_CLASS_2			**0.147** **	**0.206*****	**0.089****	**0.148*****
			(0.062)	(0.039)	(0.036)	(0.027)
RATING $_{i,t-1}$*SIZE_CLASS_3			**0.116** *	**0.186*****	**0.068***	**0.122*****
			(0.061)	(0.038)	(0.035)	(0.027)
RATING $_{i,t-1}$*SIZE_CLASS_4			**0.081**	**0.182*****	**0.057**	**0.100*****
			(0.064)	(0.041)	(0.036)	(0.028)
Test of joint significance of time dummies	χ^2(8) = 93.76***	χ^2(8) = 21.20***	χ^2(8) = 90.82***	χ^2(8) = 21.44***	χ^2(8) = 92.63***	χ^2(8) = 21.01***
Test of joint significance of industry dummies	χ^2(10) = 251.79***	χ^2(10) = 14.78	χ^2(10) = 248.32***	χ^2(10) = 14.22	χ^2(10) = 259.25***	χ^2(10) = 21.03**
Test of difference of RATING*SIZE interactions			χ^2(3) = 8.69**	χ^2(3) = 19.30***	χ^2(3) = 6.94*	χ^2(3) = 60.74***
Log-Likelihood	-4,413.42	-4,419.18	-4,402.42	-4,402.47	-3,554.75	-3,904.78
ρ					0.704	0.532
# censored observations	1,609	180	1,609	180	1,609	180

Notes: All models include an intercept (not presented). Standard errors in parentheses (clustered in pooled cross-sectional models).
*** (**, *) indicate a significance level of 1% (5, 10%). ρ indicates the share of the total variance which is due to the cross-sectional variation.

Table 5: Tobit regressions on ln(1+*INNOEXP*) and ln(1+*INV*) and *RATING*SIZE_CLASS* interactions (4,602 obs.)

	Pooled Cross Section Model		**Pooled Cross Section Model - *RATING*SIZE* classes -**		**Random-Effects Panel Model - *RATING*SIZE* classes --**	
Variable	**ln(INNOEXP)** $_{it}$	**ln(INV)** $_{it}$	**ln(INNOEXP)** $_{it}$	**ln(INV)** $_{it}$	**ln(INNOEXP)** $_{it}$	**ln(INV)** $_{it}$
$ln(SIZE_{i,t-1})$	0.221 ***	0.217 ***	0.289 ***	0.291***	0.200***	0.249***
	(0.018)	(0.010)	(0.026)	(0.017)	(0.020)	(0.013)
$ln(SIZE_{i,t-1})^2$	0.051 ***	0.055 ***	0.053 ***	0.053***	0.032***	0.044***
	(0.005)	(0.003)	(0.006)	(0.004)	(0.003)	(0.002)
$ln(AGE_{it})$	0.041	0.016	0.048	0.022	0.103***	0.072***
	(0.032)	(0.017)	(0.031)	(0.017)	(0.029)	(0.017)
$GROUP_{it}$	0.342 ***	0.203 ***	0.366 ***	0.221***	0.212***	0.194***
	(0.057)	(0.035)	(0.057)	(0.035)	(0.039)	(0.028)
$\boldsymbol{PCM_{i,t-1}}$	**0.970 *****	**0.371 *****	**0.970 *****	**0.370*****	**0.186***	**0.150****
	(0.159)	(0.092)	(0.158)	(0.092)	(0.100)	(0.071)
$\boldsymbol{RATING_{i,t-1}/100}$	**0.156 ****	**0.169 *****				
	(0.051)	(0.030)				
$\boldsymbol{RATING_{i,t-1}*SIZE\_CLASS\_1}$			**0.199 *****	**0.214*****	**0.143*****	**0.182*****
			(0.055)	(0.033)	(0.035)	(0.024)
$\boldsymbol{RATING_{i,t-1}*SIZE\_CLASS\_2}$			**0.179 *****	**0.168*****	**0.130*****	**0.135*****
			(0.055)	(0.033)	(0.034)	(0.024)
$\boldsymbol{RATING_{i,t-1}*SIZE\_CLASS\_3}$			**0.138 ****	**0.138*****	**0.111*****	**0.108*****
			(0.053)	(0.033)	(0.034)	(0.023)
$\boldsymbol{RATING_{i,t-1}*SIZE\_CLASS\_4}$			**0.108 ***	**0.129*****	**0.100*****	**0.091*****
			(0.055)	(0.034)	(0.035)	(0.024)
Test of joint significance of time dummies	$\chi^2(8) = 43.45$***	$\chi^2(8) = 21.94$***	$\chi^2(8) = 43.37$***	$\chi^2(8) = 23.09$***	$\chi^2(8) = 41.83$***	$\chi^2(8) = 23.42$***
Test of joint significance of industry dummies	$\chi^2(10) = 248.68$***	$\chi^2(10) = 15.92$	$\chi^2(10) = 247.44$***	$\chi^2(10) = 16.15$*	$\chi^2(10) = 223.65$***	$\chi^2(10) = 24.28$**
Test of difference of RATING*SIZE interactions			$\chi^2(3) = 10.71$**	$\chi^2(3) = 31.04$***	$\chi^2(3) = 6.41$*	$\chi^2(3) = 55.61$***
Log-Likelihood	-5,434.92	-4,786.68	-5,422.40	-4,758.28	-4,553.89	-4,323.08
ρ					0.683	0.466
# censored observations	1,590	270	1,590	270	1,590	270

Notes: All models include an intercept (not presented). Standard errors in parentheses (clustered in pooled cross-sectional models).
*** (**, *) indicate a significance level of 1% (5, 10%). ρ indicates the share of the total variance which is due to the cross-sectional variation.

6 Conclusions

Financing R&D activities externally may be costly due to outcome uncertainty, asymmetric information and incomplete appropriability of returns. Thus, firms may prefer to exploit internally available funds to finance their R&D investment as much as possible. However, internal funds may be limited as well. Especially small or young firms may face financing constraints for their R&D projects as they have not yet accumulated profits or a steady cash inflow from a broad and established product portfolio. Financially constrained firms may have to conduct their R&D activities at a sub-optimal level, abandon certain projects or not be able to conduct R&D at all.

From our empirical models, we draw following main conclusions. Our results show that R&D investment differs from capital investment with respect to financing constraints and the importance of internal and external resources. First, the availability of internal funds is more decisive for R&D investments than for capital investment. We observe that an increase in the availability of internal funds, measured by increases in the firms' price-cost-margin, has a larger impact on R&D investment than on capital investment. Second, smaller firms suffer more from external constraints for R&D investment than larger firms. That is, smaller firms' level of R&D investment increases as conditions for access to external funds improve, while larger firms' R&D investment is not as sensitive. Thus, financial constraints are more binding for smaller firms. Further, we find that the level of constriction decreases monotonically with firm size. Thus, the larger the firms, the fewer R&D investment projects are discarded. Larger firms may either be able to fund most of their projects internally at full scale or may face a lower gap between internal and external cost of capital. The latter argument is supported by the fact that the largest firms may offer sufficient collateral for external financing due to their overall asset value. When looking at age differences, however, we cannot not draw analogous conclusions. We do not find monotonic relationships between financial constraints and age.

In addition, intra-group financing of R&D, being a supplemental measure of internal liquidity, turns out to be another important source of funds, as the effects are considerably stronger for R&D than for capital investment.

Finally, the results are robust to a number of additional tests. All results persist in both pooled cross-sectional regressions and panel data regressions that allow controlling for firm-specific unobserved effects in the level of investment. Also robustness checks on total innovation expenditure rather than pure R&D show similar result patterns as discussed above.

As investment in new knowledge is a crucial factor in the creation of wealth, potential underinvestment is regarded as justification for government intervention to promote R&D investment from a society's point of view. This study aimed at contributing to the identification of firms that are potentially not able to pursue their R&D projects at the optimal level.

As small firms appear to be more concerned with financing constraints than larger firms, countries with well developed markets for Venture Capital and IPOs are likely to achieve a comparative advantage in R&D for high-tech or other knowledge intensive goods and services (Chiao 2002, Carpenter and Petersen 2002). Otherwise there may be room for innovation policies supporting R&D in small businesses.

Despite our effort to detect and interpret the effects of the limited financial resources for R&D investment, our study has some important limitations. We attempt to overcome the Kaplan-Zingales critique that previous studies identified financial constraints only indirectly, which is implemented by supplementing common regressions with a credit rating index that directly measures credit access. However, the panel structure of our data is not rich enough to estimate investment models that are well grounded in economic theory, such as Euler equations, accelerator models or error-correction models that all revolve around the firms' challenge to achieve an "optimal" capital stock through their investment. It would be desirable to extend the common investment models to direct measures for external constraints in the future.

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Appendix

Table A1: Tobit regressions on ln(1+*R&D*) and ln(1+*INV*) and *RATING*AGE_CLASS* interactions (5,070 obs.)

	Pooled Cross Section Model - *RATING*AGE* classes -		**Random-Effects Panel Model - *RATING*AGE* classes --**	
Variable	**ln(R&D) it**	**ln(INV) it**	**ln(R&D) it**	**ln(INV) it**
ln(SIZE i,t-1)	0.191 ***	0.224***	0.143***	0.182***
	(0.020)	(0.010)	(0.014)	(0.009)
ln(SIZE i,t-1)²	0.049 ***	0.053***	0.031***	0.042***
	(0.006)	(0.003)	(0.003)	(0.002)
ln(AGE) it	-0.0446	-0.045	0.005	0.031
	(0.080)	(0.043)	(0.051)	(0.036)
GROUP it	0.312 ***	0.177***	0.015***	0.121***
	(0.057)	(0.035)	(0.035)	(0.026)
PCM i,t-1	**1.014** ***	**0.336*****	**0.353*****	**0.153****
	(0.158)	(0.092)	(0.094)	(0.067)
RATING i,t-1*AGE_CLASS_1	**0.144** **	**0.173*****	**0.076*****	**0.131*****
	(0.060)	(0.033)	(0.035)	(0.025)
RATING i,t-1*AGE_CLASS_2	**0.126** **	**0.175*****	**0.059*****	**0.131*****
	(0.056)	(0.031)	(0.033)	(0.024)
RATING i,t-1*AGE_CLASS_3	**0.139** **	**0.179*****	**0.076*****	**0.128*****
	(0.056)	(0.031)	(0.034)	(0.024)
RATING i,t-1*AGE_CLASS_4	**0.214** ***	**0.205*****	**0.154****	**0.152*****
	(0.058)	(0.034)	(0.035)	(0.067)
Test of joint significance of time dummies	$\chi^2(8)$ = 88.52***	$\chi^2(8)$ = 23.79***	$\chi^2(8)$ = 88.35***	$\chi^2(8)$ = 24.14***
Test of joint significance of industry dummies	$\chi^2(10)$ = 312.12***	$\chi^2(10)$ = 16.17*	$\chi^2(10)$ = 376.60***	$\chi^2(10)$ = 28.15***
Test of difference of RATING*AGE interactions	$\chi^2(3)$ = 20.13***	$\chi^2(3)$ = 5.67	$\chi^2(3)$ = 40.84***	$\chi^2(3)$ = 6.84*
Log-Likelihood	-5,058.33	-5,443.54	-4,057.44	-4,864.77
ρ			0.722	0.510
# censored observations	2,414	309	2,414	309

Notes: All models include an intercept (not presented). Standard errors in parentheses (clustered in pooled cross-sectional models). *** (**, *) indicate a significance level of 1% (5, 10%). ρ indicates the share of the total variance which is due to the cross-sectional variation.

Table A2: Tobit regressions on ln(1+*R&D*) and ln(1+*INV*) and *RATING*AGE_CLASS* interactions for innovators only (4,037 obs.)

	Pooled Cross Section Model - *RATING*AGE* classes -		Random-Effects Panel Model - *RATING*AGE* classes --	
Variable	**$ln(R\&D)_{it}$**	**$ln(INV)_{it}$**	**$ln(R\&D)_{it}$**	**$ln(INV)_{it}$**
$ln(SIZE_{i,t-1})$	0.154 ***	0.216***	0.125***	0.171***
	(0.023)	(0.012)	(0.016)	(0.011)
$ln(SIZE_{i,t-1})^2$	0.050 ***	0.054***	0.032***	0.042***
	(0.006)	(0.004)	(0.003)	(0.002)
$ln(AGE_{it})$	-0.050	-0.115	0.032	0.009
	(0.083)	(0.050)	(0.055)	(0.042)
$GROUP_{it}$	0.296 ***	0.191	0.161***	0.155***
	(0.060)	(0.039)	(0.040)	(0.030)
$PCM_{i,t-1}$	**0.918 *****	**0.311*****	**0.313*****	**0.115**
	(0.173)	(0.109)	(0.101)	(0.030)
$RATING_{i,t-1}$*AGE_CLASS_1	**0.125 ****	**0.181*****	**0.060**	**0.132*****
	(0.062)	(0.038)	(0.038)	(0.030)
$RATING_{i,t-1}$*AGE_CLASS_2	**0.124 ****	**0.198*****	**0.050**	**0.136*****
	(0.057)	(0.035)	(0.036)	(0.028)
$RATING_{i,t-1}$*AGE_CLASS_3	**0.129 ****	**0.212*****	**0.050**	**0.136*****
	(0.059)	(0.036)	(0.036)	(0.027)
$RATING_{i,t-1}$*AGE_CLASS_4	**0.198 *****	**0.252*****	**0.121*****	**0.173*****
	(0.061)	(0.039)	(0.037)	(0.029)
Test of joint significance of time dummies	$\chi^2(8) = 93.44$***	$\chi^2(8) = 20.77$***	$\chi^2(8) = 92.49$***	$\chi^2(8) = 19.21$**
Test of joint significance of industry dummies	$\chi^2(10) = 254.69$***	$\chi^2(10) = 15.09$	$\chi^2(10) = 279.02$***	$\chi^2(10) = 21.09$**
Test of difference of RATING*AGE interactions	$\chi^2(4) = 13.18$***	$\chi^2(4) = 10.98$**	$\chi^2(4) = 27.56$***	$\chi^2(4) = 12.36$***
Log-Likelihood	-4,392.91	-4,405.92	-3,544.08	-3,928.54
ρ			0.732	0.589
# censored observations	1,609	180	1,609	180

Notes: All models include an intercept (not presented). Standard errors in parentheses (clustered in pooled cross-sectional models). *** (**, *) indicate a significance level of 1% (5, 10%). ρ indicates the share of the total variance which is due to the cross-sectional variation.

Table A3: Tobit regressions on ln(1+*INNOEXP*) and ln(1+*INV*) and *RATING*AGE_CLASS* interactions (4,602 obs.)

	Pooled Cross Section Model - *RATING*AGE* classes -		**Random-Effects Panel Model - *RATING*AGE* classes --**	
Variable	**ln(INNOEXP)$_{it}$**	**ln(INV)$_{it}$**	**ln(INNOEXP)$_{it}$**	**ln(INV)$_{it}$**
$ln(SIZE_{i,t-1})$	0.218 ***	0.216***	0.168***	0.179***
	(0.018)	(0.010)	(0.014)	(0.009)
$ln(SIZE_{i,t-1})^2$	0.049 ***	0.055***	0.030***	0.044***
	(0.005)	(0.003)	(0.003)	(0.002)
$ln(AGE_{it})$	-0.040	-0.030	0.015	0.054
	(0.081)	(0.043)	(0.055)	(0.038)
$GROUP_{it}$	0.334 ***	0.202***	0.200***	0.177
	(0.056)	(0.035)	(0.039)	(0.028)
$\boldsymbol{PCM_{i,t-1}}$	**0.962** ***	**0.372*****	**0.191***	**0.156****
	(0.158)	(0.092)	(0.100)	(0.071)
RATING $_{i,t-1}$****AGE_CLASS_1***	**0.161** ***	**0.161*****	**0.111*****	**0.135*****
	(0.054)	(0.032)	(0.036)	(0.025)
RATING $_{i,t-1}$****AGE_CLASS_2***	**0.141** ***	**0.165*****	**0.087****	**0.131*****
	(0.051)	(0.031)	(0.035)	(0.024)
RATING $_{i,t-1}$****AGE_CLASS_3***	**0.139** ***	**0.168*****	**0.095*****	**0.128*****
	(0.052)	(0.031)	(0.034)	(0.124)
RATING $_{i,t-1}$****AGE_CLASS_4***	**0.214** ***	**0.188*****	**0.172****	**0.145*****
	(0.055)	(0.033)	(0.036)	(0.025)
Test of joint significance of time dummies	$\chi^2(8) = 39.36$***	$\chi^2(8) = 21.78$	$\chi^2(8) = 38.62$***	$\chi^2(8) = 22.86$***
Test of joint significance of industry dummies	$\chi^2(10) = 252.82$***	$\chi^2(10) = 15.70$	$\chi^2(10) = 229.57$***	$\chi^2(10) = 23.29$***
Test of difference of RATING*AGE interactions	$\chi^2(4) = 20.95$***	$\chi^2(4) = 2.93$	$\chi^2(4) = 38.23$***	$\chi^2(4) = 4.14$
Log-Likelihood	-5,401.68	-4,782.89	-4,538.10	-4,348.61
ρ			0.680	0.464
# censored observations	1,590	270	1,590	270

Notes: All models include an intercept (not presented). Standard errors in parentheses (clustered in pooled cross-sectional models). *** (**, *) indicate a significance level of 1% (5, 10%). ρ indicates the share of the total variance which is due to the cross-sectional variation