Funding gap for innovation and firm size: an inverted u-shape relationship

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Abstract

Using the German Community Innovation Survey, we identify financially constrained firms using an ideal test. Contrary to previous studies, we find that the relationship between financial constraints and firm size is characterised by an inverted u-shape and that the group of medium-sized firms has the largest funding gaps. This last finding is explained by the fact that these firms have high innovation capabilities but, at the same time, face high capital costs. Furthermore, we test what consequences funding gaps have for subsequent productivity growth. We find negative effects of funding gaps on productivity, but only for investment in tangible capital, not innovation.

Key Words: Financial constraints, SMEs and innovation capability
JEL codes: D22, D21, D24, O31, O32

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1 Introduction

Innovation activity is an essential determination factor for productivity, competitiveness and economic growth. The role of young firms' innovation capacities has been emphasized since their innovations generate structural changes in the economy (Mina et al. 2013, Castellacci 2023). Thus, it should be a policy-level concern that restricted access to funding for innovation investments may hinder economic growth and job creation.

Furthermore, innovation investments differ from tangible investment expenditures, as they are characterized by the intangible nature of the asset being created as well as associated with a high degree of uncertainty. Thus, there is a lack of collateral that may be used as security for debt funding. These features of innovation investments make raising external funding for innovation projects more expensive in comparison to finding funds for tangible investments (Hall 2010). In addition the bulk of R&D spending is wage-based and thus offers virtually no collateral, firms must fall back on limited internal funds, so financing gaps are more severe for small and medium-sized firms (Czarnitzki & Giebel 2024). Empirical literature shows that firms tend to use internal funds over external funds when financing innovation projects (Hall 1989, 1992, Himmelberg & Petersen 1994, Bougheas et al. 2003, Czarnitzki & Hottenrott 2011). Overall, the theoretical and empirical literature suggests that financial constraints depend not only on information asymmetries and moral hazard problems but also on other firm characteristics (Petersen & Rajan 1995, Czarnitzki 2006, Czarnitzki & Hottenrott 2009, Brown et al. 2012) such as borrower-lender relationships (Martinelli 1997, Berger & Udell 2002) and other institutional factors (Hall 1992, Bloch 2005, Bhagat & Welch 1995). Drawing on a systematic review of 48 studies, (Romero Alvarez et al. 2025) show that while bank credit remains the dominant external source for SME innovation, its usefulness—as well as that of public subsidies or crowdfunding—depends critically on firms' technological capability and the surrounding institutional environment, confirming that financing gaps are highly context-specific.

A neglected factor in the empirical literature that may have an impact on financial constraints for innovation investment is the concept of innovation capability. That is, a firms' capacity to generate and achieve new innovation projects is an one of the important determinant factors for financial constraints.

To the best of our knowledge, Hottenrott & Peters (2012) were first to relate the concept of innovation capability to financial constraints. Their paper is based on innovation survey data from Mannheim that measures liquidity constraints on innovation investment directly. In their survey, firms are offered additional hypothetical liquidity and asked whether they would invest in innovation projects or use the additional liquidity for other expenditures. If the firm chooses to invest in additional innovation projects, it is an indication that the firm has unpursued investment opportunities that are not profitable enough to garner external funding. Their results show that financial constraint depends on innovation capability. Building on a similar survey-experiment, Czarnitzki & Giebel (2024) extend the ideal-test approach with the 2014 German CIS and show that severe financing constraints are largely confined to young, innovation-intensive firms, while most shelved R&D projects carry only modest private returns.

This paper is a further development of the approach pioneered by Hottenrott & Peters (2012). First, we modify the methodology by using an additional survey question in which the firm is offered credit with a comparatively attractive interest rate instead of additional exogenous equity. Adding this second question re-ensures consistency in the firms' response. If the firm chooses to invest in innovation projects when offered additional equity and credit indicates that the firm has financial needs for both internal funding and discounted external funding, the firm is financially constrained. The fundamental argument is based on the pecking order theory, where internal funding should be preferred over external funding since it is less expensive (Myers & Majluf 1984). Thus, the firm still chooses to invest despite the more expensive source of funding. According to Hall & Lerner (2010), this is an ideal way of measuring financial constraint, as it is a direct measure derived from survey data.

We focus on firm size in addition to innovation capability as a determination factor for financial constraint. Prior research shows that financial constraints tends to be more severe for smaller firms[1]. The fundamental argument is based on the fact that young firms are subject to greater informational asymmetries, leading to credit rationing and moral hazard problems. Younger firms are associated with less collateral and shorter track records. Moreover, older firms can benefit from established bank lending relationships, where asymmetric information can be reduced Berger & Udell (2002). Large, established firms can take advantage of accumulated profits as well as build and extend on prior innovation projects, while younger firms lack accumulated profits and may need to conduct more fundamental innovation that, in turn, may require more resources Czarnitzki & Hottenrott (2009). Moreover, bank funding may be more restricted for young, small firms that engage in innovation conduction due to the high uncertainty associated with innovation projects and the higher default risk of such firms Fritsch et al. (2006). In summary, the literature suggests that innovation investments are subject to financial constraints. These constraints may be even more severe for small young firms that may have higher capital costs in comparison to their larger counterparts. Thus, the empirical literature has focused on size

[1] See, e.g., Petersen & Rajan (1995), Berger & Udell (2002), Carpenter & Petersen (2002), Czarnitzki (2006).

classifications, mainly by classifying small and medium enterprises (SMEs). However, to gain insight into how financial financial constraints can be tackled, a higher degree of differentiation of size classes is needed. Moreover, new empirical evidence covering the post-crisis period is necessary to investigate how the financial crisis affected financial constraints and whether the impact was different for different size classes.

Furthermore, financial constraints can hamper productivity growth by impeding optimal resource allocation, perhaps ultimately leading to reduced competition, capital investment and technology adoption. The channel of impact depends on the type of financial friction and country. Thus, we test empirically whether financial constraints have an impact on firms' productivity. Finally, we compare innovation investments with tangible investment expenditures and add the 2014 wave of the survey data. Theoretically, financial constraints for investment in innovation projects should be more severe since access to funding is particularly difficult for such projects due to greater information asymmetries and higher uncertainty.

Overall, these improvements yield a better identification of financially constrained firms, which, in turn, allows for more precise and improved policy suggestions. Furthermore, we can study the change in financial constraints over time and how it is affected by various variables.

Our results show that the relationship between a firm's financing gap and firm size is in fact represented by an inverted u-shape. Moreover, being financially constrained in terms of tangible investments reduces the productivity level, while there is no impact on productivity for firms who are financially constrained in terms of innovation.

The rest of the paper is organized as follows. Section 2 provides the theoretical and empirical background. Section 3 contains the data and model specifications. Next, Section 4 presents our estimation results. Finally, Section 5 provides the discussion and conclusion.

2 Literature review

2.1 Theoretical framework

In principal, a firm has two available funding sources, namely, internal and external funding. Essentially, internal funding consists of a firm's retained earnings, while external funding consists of various debt contracts. In an imperfect capital market, the investment market will suffer from information asymmetries, leading to credit rationing, moral hazard and adverse selection problems. Thus, if credit suppliers have less information regarding the quality of an investment project, then they are forced to charge a risk premium. This creates a wedge between the cost of internal and external funding. Firms face a hierarchy of financial funding sources where funds with lower cost will be used first. Thus, internal cash flow is preferred over debt, and debt is preferred over equity (Myers & Majluf 1984, Hall et al. 2009). Given that internal cash flow is not infinite, firms may need additional external capital. However, due to market imperfections, firms with potentially profitable investment opportunities may not be able to implement them. Thus, a firm is considered to be financially constrained if its investment is restricted by its access to internal funds and its inability to acquire sufficient external funding (Mina et al. 2013).

In order to illustrate how a firm's innovation capability affects financial constraints, a basic model is derived based on models of firm investment behaviour by Howe & McFetridge (1976) and David et al. (2000).

In this model, it is assumed that each firm has a set of innovation projects that, in turn, are determined by each firm's innovation capability (IC), that is, a firm's ability to create and implement innovation. These innovation projects are ranked according to their projected marginal rate of return in descending order. Thus, the marginal rate of return is reflected by a downward-sloping demand curve for innovation funding. This relationship is illustrated in Figure 1, where the marginal cost of capital and marginal rate of return are plotted on the vertical axis and the number of innovation projects on the horizontal axis. The upward-sloping marginal cost of capital reflects a firm's opportunity cost of investment. When innovation investment increases, firms shift from internal funding (retained earnings) to external funding (debt and/or equity), which tends to push the marginal cost of capital upwards. This increase in the marginal costs would be the case even if innovation investments could be financed entirely by internal funding. As firm's innovation investments increase, the firm would eventually have to fund its tangible investments with external funding. Thus, the flat range of the upward slope of the marginal cost of capital in Figure 1 reflects the internal use of capital, while the increasing range reflects the use of external funding. In terms of maximizing profits, firms' innovation investments will occur at the point where the marginal rate of return equals the marginal cost of capital. Area A in Figure 1 reflects potential innovation investment that is not profitable enough to be pursued with internal funding.

The marginal rate of return (MRR) may be described as a function of innovation expenditures (IE), innovation capability (IC) and other firm characteristics (FC). While the marginal cost of capital (MCC) is a function of IE, alternative investment opportunities (IO), the amount of available internal funds (IF) and other firm characteristics[2] (FC):

$$MRR_i = f(IE_i, IC_i, FC_i) \quad (1)$$

[2]Given an imperfect capital market, the cost of capital will be affected by other firm characteristics such as capital structure and creditworthiness.

$$MCC_i = f(IE_i, IO_i, IF_i, FC_i). \tag{2}$$

If a firm receives additional exogenous equity capital[3], how does doing so affect innovation investments? If a firm has already reached its optimal level of innovation investment using only available internal funds, additional exogenous equity will not affect innovation investments. Thus, if a firm does not increase investments, may be due to: i) being faced with the same cost of capital, indicating a perfect capital market; or ii) having no profitable innovation projects given the internal cost of capital, indicating an imperfect capital market. In both cases, the firm is not financially constrained, as shown in Figure 1. However, if a firm would actually increase its innovation investments, then one could reject both hypotheses. Thus, the cost of internal and external funding is not the same, indicating an imperfect capital market and implying that the firm is investing at a sub-optimal level. Hence, the firm is financially constrained. Figure 2 illustrates a financially constrained firm that is exposed to exogenous equity capital, and area B indicates the potential innovation investments that could have been made but were impossible due to financial constraints.

Now, we consider two firms, X and V, where firm X has a higher innovation capability, i.e., firm X has the ability to transform innovation ideas with a higher rate of return in comparison to firm V. Thus, firm X has a higher demand for funding. Hence, firm X has a flatter demand curve than firm V. The higher the innovation capability, the higher the probability of innovation investment when given exogenous equity capital. Given that firms X and V receive the same amount of exogenous equity capital, the impact will be larger for firm X than firm V. This is illustrated in Figure 3, where areas X and V indicate the set of innovation projects that are not profitable enough to pursue with external funding for firms X and V, respectively. Areas X* and V*

[3] Assuming that this is not due to increased future demand.

illustrate the additional innovation investments that are conducted by firms X and V, respectively, given an exogenous equity shock.

Now, instead, we assume that both firm X and V have the same innovation capability. However, firm X has a lower level of internal funding, which essentially implies that firm X has a higher cost for external funding. Thus, if both firm X and V receive the same amount of external equity, the effect will be larger on firm X's innovation investment (see Figure 4).

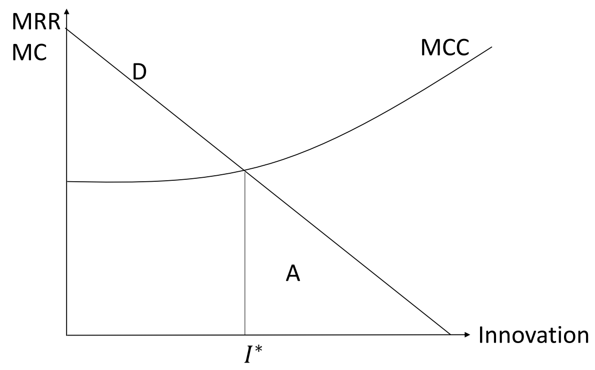

Figure 1: Unconstrained firm

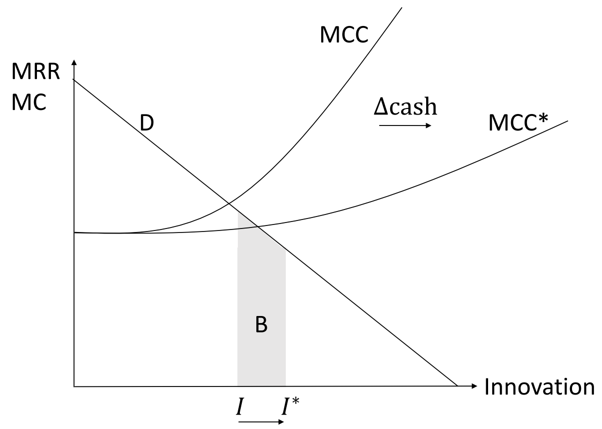

Figure 2: Constrained firm

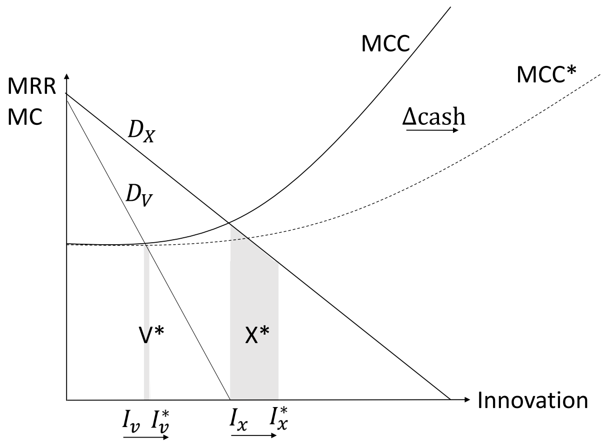

Figure 3: $IC_X > IC_V$

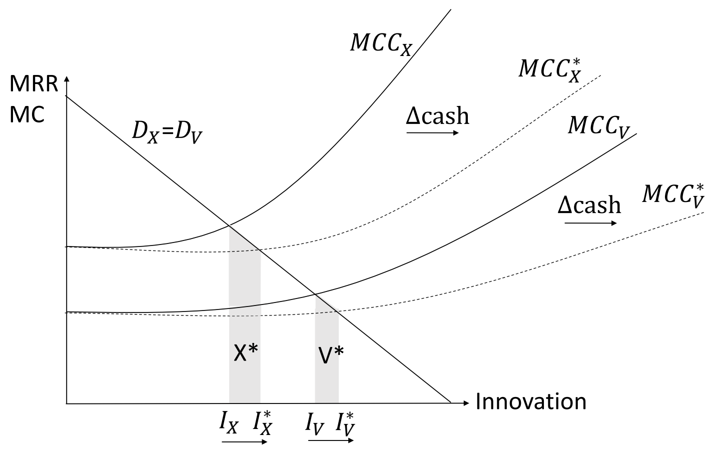

Figure 4: $IF_X < IF_V$

2.2 Empirical background

Empirical findings, such as Himmelberg & Petersen (1994), Petersen & Rajan (1995), Berger & Udell (2002), Czarnitzki (2006), Ughetto (2008) and (Czarnitzki & Hottenrott 2009), show that smaller firms (measured either as firm age, number of employees or assets) are more likely to be subject to financial constraints than their larger counterparts since they are not as capital intensive and cannot provide as much collateral. On the other hand, (Savignac 2008) uses French data to show that financial constraints decrease with firm size and depend essentially on the firms' ex-ante financing structures. Furthermore, according to Hyytinen & Toivanen (2005), small and medium firms that are dependent on external funding tend to innovation less in comparison to firms that are not dependent on external funding. Muller & Zimmerman (2008) provide evidence that younger firms tend to have less equity capital, which may increase interest rates that are demanded by credit suppliers. Petersen & Rajan (1995) and Berger & Udell (2002) show that problems of asymmetry tend to be more severe for younger firms since they have not yet established a bank-lending relationship. Thus, older firms benefit from long-term borrower-lender relationships as information asymmetric is mitigated. Moreover, using survey data, Stoneman & Canepa (2002), Savignac (2008) and Schneider & Veugelers (2008) argue that banks may be reluctant to finance innovation projects for younger firms due to the high default risk. Thus, Egeln et al. (1997) and Petersen & Rajan (1994) provide evidence for start-ups being financially. constrained.

3 Empirical approach

3.1 Data

The Mannheim innovation panel data (MIP) is a database provided by the Centre for European Economic Research (ZEW). The MIP database has been built on behalf of the German Federal Ministry of Education and Research since 1993 and is a part of the Europe-wide Community Innovation Surveys (CIS). The annual innovation survey contains important information regarding new products, improved products, services and expenditures for innovation. We use the 2007 and 2014 waves since these contain the same questions regarding additional funding capital. The questions asked in the survey take into account the firms' investment behaviours for the past three years. Thus, the 2007 and 2014 waves contain the aggregated survey outcomes for the 2004 - 2006 and 2011 – 2013 periods, respectively.

Innovation projects are defined as new or significantly improved products, services and/or in-house processes. Other investment expenditures refer to any investments made in fixed and/or intangible assets. Table 1 provides the definitions of the variables used in the empirical model.

Table 1: Variable definitions

Variable name	Definition
fc	Financial constraint with $fc \in [0, 1, 2]$
tfp	Total factor productivity measured as value added
IC	Innovation capability measured by three categories
Size classes	Firm size by number of employees measured as a categorical variable
Employees	Firm size by number of employees measured as a continuous variable
Controls	Industry, firms size, located in east or west Germany, employees with university degree, age of a firm and firm type
Industry	NACE 2-digit industry code, 21 industries

The variable financial constraint (fc) is derived from the two following survey questions: i) assuming your company had at its disposal an unexpected additional profit or additional equity capital of 10% of last year's turnover, which possibilities for resource allocation would your enterprise choose most probably?, and ii) assuming instead of the unexpected additional profit/additional equity capital, your company had access to credit in the same amount with a comparatively attractive interest rate, would your enterprise implement the considered investments/innovation projects as well? The response options are presented in Table 2. By selecting option A and/or B in survey question one, the firm insinuates that the marginal profit of such an investment is expected to be higher than the other options. Moreover, it indicates that the firm has unpursued investment opportunities and a positive financial need for internal funding. Selecting A and/or B for both the first and second survey questions indicates that the firm has a positive financial need for discounted external funding and that the firm is financially constrained. These points are based on the pecking order theory, where internal funding should be preferred over external funding since it is less expensive (Myers & Majluf 1984). Thus, the firm chooses to still invest despite the more expensive source of funding offered. A firm will only double select if innovation capability exceeds available internal funds and external funding is more expensive in comparison to the offered loan. Firms who only select option A and/or B in survey question one have a positive financial need only for additional internal funding. Any other combination of the response options indicates zero financial need. Thus, fc ranges from zero to two, $fc \in [0, 1, 2]$:

- Neither A nor B is selected in survey question one $fc = 0$
- A and/or B is selected in survey question one but not in survey question two $fc = 1$
- Double selection of A and/or B $fc = 2$

Table 2: Response option for survey question one and two

Response option for survey question one	
A	Implementation (of additional) investments
B	Implementation (of additional) innovation projects
C	Retention/accumulation of reserves
D	Payout of proprietors (incl. repayments of shareholders' loans)
E	Payment of liabilities (e.g payment of bank credits, supplier credit)
F	No estimation possible
Response option for survey question two	
A	Implementation of investments
B	Implementation of innovation projects
C	No, rather improbable
D	Estimation impossible

The variable innovation capability (IC) is a categorical variable derived from the third survey question and refers to a firm's capacity to generate innovation. This question shows how often a firm conducts in-house R&D were the response options are:

- Continuous R&D
- Occasional R&D
- No R&D activity

Furthermore, total factor productivity (tfp) is measured using Wooldridge's (2009) approach. A set of control variables is used in the model. Following previous empirical literature, the financial constraints are assumed to be affected by firm size and firm age. In order to detect a possible non-linear relationship between firm size and financial constraint, we add squared log employees to the estimation model as well as seven size classes (see Table 3). Doing so allows for testing various specifications of the size effect. Firm age is represented by a dummy variable indicating whether a firms is younger than 3 years or not. Firms located in East Germany are subject to more subsides and might therefore face lower financial constraints (Czarnitzki 2006). Hence, we include a dummy variable indicating the geographical location of a firm in either West or East Germany. Moreover, we control for differences in innovation and investment intensity across industries (Table 4). The primary expense involved in innovation investment consists of salaries for highly skilled employees. Thus, we include the share of employees with a university education as a proxy for a firm's human capital intensity. Furthermore, we control for firm type, which refers to the legal company form. Table 5 presents the legal firm types separated by firm size. Different firm types have access to different sources of funding, as, for example, public equity and bond markets are only available to listed corporations.

Table 3: Seven size classes by amount of employees

Number of employees	Size category
0< employees ≤ 19	1
20 ≤ employees ≤ 49	2
50 ≤ employees ≤ 99	3
100 ≤ employees ≤ 249	4
250 ≤ employees ≤ 499	5
500 ≤ employees ≤ 999	6
10000 ≤ employees	7

Table 4: Industry category by size for 2013 (%)

Industry	Firm size			
	<50	50-249	>250	All
Mining	3.2	4.4	5.7	3.9
Food, tobacco	4.7	5.5	3.7	4.8
Textiles	4.5	3.1	1.3	3.7
Wood, paper	3.2	4.7	1.9	3.4
Chemicals	2.3	4.0	5.4	3.2
Plastics	2.7	4.3	3.0	3.1
Glass, ceramics	2.0	2.6	3.8	2.4
Metals	6.8	8.4	5.8	7.1
Machinery	4.9	8.1	7.4	6.0
Electrical equipment	2.5	6.5	9.8	4.5
Medical, instruments	1.5	3.2	6.1	2.6
Transport equipment	6.2	7.2	3.4	6.1
Furniture	6.3	4.9	3.7	5.6
Wholesale	4.2	2.8	2.8	3.7
Retail, automobile	8.1	8.7	7.5	8.2
Transport, communications	5.1	4.6	2.6	4.6
IT, telecom	3.3	2.8	10.0	4.0
Technical services	7.4	3.1	1.3	5.4
Firm-related services	7.1	1.7	2.0	5.1
Other services	4.9	4.4	8.3	5.2
n.a.	9.1	4.9	4.4	7.4
Total	100.0	100.0	100.0	100.0
Obs	3,235	1,374	702	5,311

Table 5: Legal company forms for 2013 (%)

Legal	Firm size			
form	<50	50-249	>250	All
1	27.3	9.8	9.6	20.4
2	13.6	22.2	23.8	17.2
3	57.9	65.4	53.5	59.2
4	1.3	2.6	13.1	3.2
Total	100.0	100.0	100.0	100.0
Obs	3,232	1,372	701	5,305

1=sole proprietorship, partnership

2=trade partnership, limited company

3=limited liability corporation (GmbH)

4=listed corporation (AG)

3.2 Descriptive statistics

Tables 6 and 7 present the variable fc by year and firm size for innovation projects and investment expenditures, respectively. In 2014, for innovation projects, 48.2% of the firms reported that they were not financially constrained ($fc = 0$), which is an increase of 5.8% from 2007. For tangible investments, the amount of firms who reported that they were not financially constrained nearly doubled from 10.4% to 20.1%. For innovation projects, we observe a reduction in ($fc = 1$) from 34.6% to 33.1% and a somewhat larger fluctuation for other tangible investments from 46.4% to 42.6%, which implies a decline in internal financial constraints. The number of firms who would invest in further innovation projects and tangible investment projects if given additional external funding ($fc = 2$) declined from 23.0% to 18.8% for innovation projects and from 43.2% to 37.3% for other investment expenditures.

Overall, there has been a reduction in financial constraints for both innovation projects and tangible investment expenditures from 2007 to 2014. Moreover, comparing innovation projects with tangible investment expenditures, one may observe that there are more tangible investment opportunities than innovation projects that are not pursued. It is noteworthy that in 2014, more than twice as many companies reported ($fn = 2$) for tangible investment expenditures in comparison to innovation projects, thus indicating that tangible investment expenditures may be, on average, more financially constrained.

When evaluating the descriptive statistics according to size, we see that, in 2014, for innovation projects, more than half (53.7%) of the smallest firms reported that they were not financially constrained ($fc = 0$), which is an increase of 6.3% from 2007. Thus, for innovation projects, the smallest firms are the least financially constrained. For tangible investment expenditures, the opposite is observed since the largest firms reported being the least financially constrained ($fc = 0$). For innovation projects, there has been a reduction in $fc = 1$ among size categories 1 and 3, while an increase is observed for size category 2. Thus, $fc = 1$ is more common among medium-sized firms. For tangible investment projects, a decrease is observed among all size categories, where ($fc = 1$) is most common among the smallest firms. For all size categories, a reduction in $fc = 2$ is observed for both innovation projects and tangible investment expenditures, which is also strongest for medium-sized firms.

Table 6: Share of financially constraint firms (%) for investment expenditure by year and size

size	<50		50-249		>250		All	
year	2007	2014	2007	2014	2007	2014	2007	2014
fc1=0	11.3	21.9	8.4	13.6	11.5	26.4	10.4	20.1
fc1=1	47.6	43.4	44.0	42.7	47.2	37.8	46.4	42.6
fc1=2	41.2	34.7	47.6	43.7	41.3	35.8	43.2	37.3
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
#obs	1,392	1,444	813	646	436	246	2,641	2,336

Table 7: Share of financially constraint firms (%) for innovation expenditure by year and size

size	<50		50-249		>250		All	
year	2007	2014	2007	2014	2007	2014	2007	2014
fc2=0	47.4	53.7	40.1	38.2	32.7	42.5	42.4	48.2
fc2=1	31.1	30.1	34.4	38.4	44.2	36.3	34.6	33.1
fc2=2	21.5	16.2	25.5	23.4	23.1	21.2	23.0	18.8
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
#obs	990	1,047	593	458	364	212	1,947	1,717

Table 8 presents the variable innovation capability (IC) by year and size. Nearly two- thirds of the firms reported that they have never conducted any R&D. There has been an increase the number of firms never conducting R&D, and there has also been an increase in the number of firms engaging in continuous and occasional R&D. The smallest firms are most likely to not be engaged in any R&D, while the largest firms are the firms that are most likely to conduct continuous R&D. Occasional R&D is most common among medium-sized firms. While a reduction in continuous R&D is observed for the smallest firms, an increase is observed for the medium-sized and large firms. Occasional R&D engagement has decreased among all size categories.

Table 8: Innovation capability by size and year

size	<50		50-249		>250		Total	
year	2007	2014	2007	2014	2007	2014	2007	2014
never	77.5	81.8	62.4	61.9	42.8	45.3	67.0	71.8
occasionally	11.2	7.3	16.1	12.6	11.6	8.3	12.7	8.8
continuously	11.4	10.9	21.2	25.5	45.6	46.4	20.3	19.4
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
#obs	3051	3235	925	1374	580	702	4556	5311

Table 9: Descriptive statistics of variables in the model

variable	N	mean	sd	min	max
fc1	3227	1.28	0.68	0	2
fc2	2415	0.76	0.78	0	2
logemp	3380	3.79	1.62	0	11.64
logemp^2	3380	16.97	14.26	0	135.4
r&d never	3380	0.63	0.48	0	1
r&d cont	3380	0.23	0.42	0	1
r&d occas	3380	0.13	0.34	0	1
human cap	3380	18.28	22.79	0	100
east	3380	0.36	0.48	0	1
fambes	3380	0.61	0.49	0	1
young	3380	0.03	0.17	0	1
firmtype=1	3380	0.16	0.37	0	1
firmtype=2	3380	0.19	0.39	0	1
firmtype=3	3380	0.62	0.49	0	1
firmtype=4	3380	0.03	0.17	0	1

3.3 Empirical model

Equation (3) describes a firms' financial constraints for investment expenditures and innovation projects at time t as a function of innovation capability (IC), firm size and controls. Firms size is estimated both as a continuous variable and as a categorical variable [4]. When measuring firm size as a continues variable the number of employees in a firm is used. Moreover, in order to detect a non-liner relationship between firm size and financial constraint firm size as a continues variable is squared, $employees^2$.

Following previous research, our control variables consist of industry type, firm type, firm age, number of employees with a university degree and whether a firm is located in West or East Germany. Financial constraint (*fc*) is a ordinal categorical variable, $fc \in [0, 1, 2]$. Thus, an ordinal probit model is used, where fc_t^* denotes the latent financial constraints for investment expenditures and fc_t^* denotes the latent financial constraints for innovation projects. μ_1 and μ_2 are the intercepts of the model.

$$fc_{kt}^* = f(IC, size, employees, employees^2, controls) + \varepsilon_{kt} \tag{3}$$

where:

$$fc_t = 0 \text{ if } fc_t^* \leq \mu_1$$

$$fc_t = 1 \text{ if } fc_t^* \; \mu_1 < fc_{it}^* \leq \mu_2$$

$$fc_t = 2 \text{ if } fc_t^* \leq \mu_2$$

Roodman's conditional mixed process (CMP) is applied in STATA[5] to es-

[4]See table 3 for definition of firm size as a categorical variable.
[5]See e.g.,Roodman (2009)

timate equation (3). The CMP model has several advantages. First, it is a seemingly unrelated regression (SUR) estimator, which allows several equations to be estimated simultaneously using a system approach in which the error terms are allowed to be correlated. Taking such correlation into account mitigates the omitted variable bias. Furthermore, it is a flexible model for which the dependent variable may be binary, censored, interval, or continuous, and it also allows each equation to vary by observations.

In the next step the affect of financial constraint on firms productivity is estimated. We use total factor productivity (tfp) which is defined as the ratio of total output to the weighted sum of production inputs. Total output is measured as value added and material cost is used as a proxy for intermediate inputs. How to estimate total factor productivity has been a well discussed issue in applied economics. An essential issue in estimating production functions is the endogeneity that may occur due to correlation between the unobserved productivity shocks and observed input levels, resulting in biased estimates from ordinary least squares(OLS). Thus, a natural response to a productivity shock is to increase the level of output by increasing the level of input. In order to avoid this bias, Wooldridge (2009) estimation method is used. The Wooldridge (2009) approach uses generalized method of moments (GMM) where the two equations have the same dependent variable but different instruments. This method solves the identification problem and accounts for both serial correlation and heteroscedasticity.

Equation 4 describes a firm's total factor productivity as a function of financial constraints (*fc*), size and control variables. Size is only estimated as a categorical variable. tfp_{t+1} denotes the total factor productivity for tangible investment expenditures and innovation projects. In order to estimate how financial constraints affect firm productivity, the equations are forwarded one time period. Thus, for the survey period 2011-2013, $t+1$ refers to 2014. However, for the survey period 2004-2006, $t+1$ refers to 2008 due to lack of data for 2007.

$$tfp_{t+1} = f(fc_t^* \, size, controls) + \epsilon_t \tag{4}$$

4 Results

4.1 Estimation Results

Equation 3 is estimated using an ordinal probit model solved in a simultaneous equation system for both tangible investments and innovation projects. Table 10 presents the estimation results, where fc_1 denotes the financial constraints for tangible investments and fc_2 for innovation investments. The positive and significant $atanh_{(}\rho_{12})$ denotes the correlation between the error terms, which confirms the importance of using a system estimator. The negative and significant year coefficient indicates that financial constraints have decreased relative to 2007 for both investment projects and tangible investment expenditures.

In the first column, we control for firm size as a continuous and squared variable, while, in column two, we control for size as a categorical variable with seven classes. Column three adds bank loan (bank) and internal funding (cash) as control variables.

The innovation capability coefficient (r&d cont and r&d occa) is positive and significant for both tangible and intangible expenditures, entailing that the probability of being financially constrained is positively related to innovation capability. Firms with occasional and continuous R&D are more financially constrained compared to firms with no R&D. This result is in line with Hottenrott & Peters (2012). However, there is no significant difference between firms which perform R&D continuously and firms which perform

R&D occasionally.This is true for both tangible and intangible expenditures.

Furthermore, $ln(emp)$ (which measures size as a continuous variable) is positive and significant, while $(ln)emp^2$ is negative and significant. These results imply that the relationship between financial constraint and firm size is not linear but, in fact, inverse u-shaped for both tangible investments and innovation projects. This result is confirmed in column two (Table 10), where the probability of being financially constrained is highest among medium-sized firms and lowest among the smallest and largest firms. Thus, medium sized firms with high innovation capability are more likely to be financially constrained. The relationship between firm size and financial constraints is a well-explored field within investment literature (Fazzari et al. 1988, Kadapakkam et al. 1998, Carpenter & Petersen 2002), where smaller firms are more financially constrained then their larger counterparts. However, the majority of previous research has been based on U.S. manufacturing data. Thus, there is a lack of research investigating in detail how firm size affects financial constraints using non-manufacturing European data.

Furthermore, including variables for internal and external (cash=yes and bank=yes) funding confirms that firms with high innovation capability that use external funding (for both tangible and intangible expenditures) are more likely to be financially constrained than firms that use internal funding. Given the high degree of uncertainty and lack of collateral for innovation projects may make it harder and more expensive to raise external capital. Moreover, certain projects may be profitable if funded at the internal rate of return, but not worthwhile if funded with external capital, given the risk premium on the cost of external capital. Young firms (young=yes) with high innovation capability and expenditures in intangible assets are more likely to be financially constrained. However, for tangible expenditures firms are only more likely to be more financially constrained if funded with external funding. The problem of asymmetric information is more severe among small firms with intangible investments. Lack of information, collateral and shorter track-records makes younger firms more exposed to credit rationing. Thus our result shows that, firms with high innovation capability with intangible expenditures and/or low financial resources are more likely to be constrained.

The coefficient for share of employees with a university degree (humancap) is negative and significant for tangible investment expenditures. Thus,the probability of being financially constrained decreases as the share of employees with a university degree increases for firms with high innovation capability with tangible expenditures. However, the coefficient for share of employees with a university degree for firms with intangible expenditures is insignificant. Thus, share the share of employees with with a university degree have no effect on firms with high innovation capability with intangible expenditures. Previous research shows that human capital (employees with a university degree) can reduce financial constraints on innovation expenditures. Moreover, human capital allows innovation investments to generate a long-term competitive advantage D'Este et al. (2014), Peng et al. (2020). Family owned firms (fambes=yes) with high innovation capability are more likely to be financially constrained than other ownership structure. This yields for both tangible and intangible innovation expenditures. On one hand family owned businesses may have a well established relationship with their bank. However, empirical research shows that family owned enterprises don't want to dependent on external financing and therefore prefer internal funding Hottenrott & Peters (2012), Peters & Westerheide (2009), Dreux IV (1990), De Visscher et al. (2011).

In order to control for regional differences [6] we include a control variable that establishes Whether the firm is located in east or west Germany. Our

[6]During the 1990s and early 2000s firms located in East Germany were subject to wide R&D subsidy programs, thus they faced lower financial constraints. Czarnitzki & Licht (2006)

result shows that firms located in east Germany (east=yes) with a high innovation capability and expenditures in tangible investments have are more likely to be financially constrained. However, the location of the firm for intangible expenditures as no impact.

In the next step, we analyse how financial constraints affect productivity. Table 11 presents the estimation result, as specified in equation (4). A Hausman test has been performed which shows that the random effects model is not rejected. Thus, we use between, fixed and random effects. Our result shows that financial constraints for tangible investment expenditures reduce the productivity level, while financial constraints has no impact on the productivity of intangible expenditures. The insignificant year coefficient indicates that there has been no change in the level of productivity. Moreover, productivity is positively linked to financial constraints and firm size.

In sum, there has been a reduction in investment opportunities that have not been pursued, thus financial constraints have decreased since 2007. However, firms with higher innovation capabilities are more likely to face financial constraints. Moreover, the relationship between firm size and financial constraints is characterized by an inverse u-shape. Furthermore, there has been no change in the level of productivity. However, firms who are financially constrained for tangible investment expenditures have a lower level of productivity, while financial constraints involving innovation projects have no impact on productivity.

Table 10: CMP estimation of equation system

	(1)	(2)	(3)
Equation 1: fc1			
year 2013	-0.286***	-0.302***	-0.155***
	[0.052]	[0.053]	[0.050]
ln(emp)	0.252***	—	0.188***
	[0.056]		[0.059]
$\ln(emp)^2$	-0.024***	—	-0.019***
	[0.006]		[0.006]
size 50-249	—	0.210***	—
		[0.056]	
size ≥250	—	-0.055	—
		[0.077]	
cash=yes	—	—	-0.101
			[0.064]
bank=yes	—	—	0.368***
			[0.049]
r&d cont	0.199***	0.243***	0.163**
	[0.069]	[0.069]	[0.065]
r&d occa	0.226***	0.244***	0.160**
	[0.073]	[0.074]	[0.069]
humancap	-0.005***	-0.006***	-0.003**
	[0.001]	[0.001]	[0.001]
east=yes	0.199***	0.192***	0.130**
	[0.052]	[0.052]	[0.051]
fambes=yes	0.177***	0.152***	0.169***
	[0.052]	[0.052]	[0.051]
young=yes	0.222	0.204	0.310**
	[0.138]	[0.138]	[0.140]
firmtype=2	-0.149*	-0.082	-0.124
	[0.085]	[0.084]	[0.088]
firmtype=3	-0.119*	-0.067	-0.096
	[0.070]	[0.069]	[0.073]
firmtype=4	-0.050	0.014	-0.022
	[0.155]	[0.154]	[0.146]
industry FE	yes***	yes***	yes
firm RE	yes***	yes***	no

(*Continue next page*)

Equation 2: fc2			
year 2013	-0.119**	-0.132**	-0.006
	[0.057]	[0.057]	[0.071]
ln(emp)	0.127**	—	0.071
	[0.060]		[0.077]
ln(emp)^2	-0.011*	—	-0.009
	[0.007]		[0.008]
size 50-249	—	0.118*	—
		[0.061]	
size ≥250	—	-0.086	—
		[0.082]	
cash=yes	—	—	-0.137
			[0.107]
bank=yes	—	—	0.321***
			[0.090]
r&d cont	0.885***	0.930***	0.352***
	[0.097]	[0.100]	[0.086]
r&d occa	0.837***	0.852***	0.266***
	[0.098]	[0.099]	[0.089]
humancap	0.002	0.001	-0.001
	[0.001]	[0.001]	[0.002]
east=yes	0.013	-0.001	0.075
	[0.056]	[0.056]	[0.070]
fambes=yes	0.291***	0.270***	0.265***
	[0.060]	[0.060]	[0.069]
young=yes	0.484***	0.471***	0.694***
	[0.153]	[0.153]	[0.191]
firmtype=2	0.050	0.094	0.133
	[0.097]	[0.096]	[0.133]
firmtype=3	0.104	0.132	0.198*
	[0.083]	[0.082]	[0.117]
firmtype=4	0.107	0.164	0.296
	[0.161]	[0.158]	[0.180]

(*Continue next page*)

industry FE	yes***	yes***	yes*
firm RE	yes***	yes***	no
μ_{11}	-0.943***	-1.416***	-1.020***
	[0.174]	[0.154]	[0.190]
μ_{12}	0.616***	0.151	0.492***
	[0.172]	[0.135]	[0.189]
μ_{21}	0.983***	0.727***	-0.093
	[0.217]	[0.178]	[0.308]
μ_{22}	2.142***	1.890***	1.280***
	[0.261]	[0.222]	[0.309]
$\log \sigma_1$	-0.699**	-0.665**	—
	[0.283]	[0.270]	
$\log \sigma_2$	-0.860*	-0.843*	—
	[0.498]	[0.487]	
atanh ρ_{12}	0.806***	0.798***	0.790***
	[0.126]	[0.126]	[0.041]
Observations	3380	3380	2738
df(m)	64	64	68
χ^2	243.68	240.61	322.25
p	0.000	0.000	0.000

Standard errors in brackets * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Column 1 controls for firm size as a continuous and squared variable.

Column 2 controls for size as a categorical variable with seven classes.

Column 3 adds bank loan and internal funding as control variables.

Firm fixed effect not possible due to two periods, thus random effect is used.

Table 11: Productivity effects of financial constraints

	(1) tfp BE	(2) tfp FE	(3) tfp RE
$fc1_{t-1}$	-0.092***	-0.048	-0.090***
	[0.027]	[0.126]	[0.026]
$fc2_{t-1}$	0.005	-0.030	0.006
	[0.026]	[0.121]	[0.026]
year 2014	0.047	0.112	0.054
	[0.037]	[0.099]	[0.035]
size=2	0.036	-0.100	0.022
	[0.050]	[0.428]	[0.050]
size=3	0.286***	0.021	0.271***
	[0.054]	[0.848]	[0.054]
size=4	0.379***	0.003	0.378***
	[0.054]	[1.029]	[0.054]
size=5	0.551***	0.264	0.534***
	[0.070]	[0.820]	[0.069]
size=6	0.692***	0.302	0.671***
	[0.096]	[0.750]	[0.093]
size=7	0.949***	0.000	0.921***
	[0.105]	[.]	[0.106]
Constant	0.785***	0.934**	0.789***
	[0.045]	[0.388]	[0.044]
Observations	1051	1051	1051
df(m)	9	996	9
χ^2			200.79

Standard errors in brackets * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
BE denotes between effects, FE effects and RE random effects.
Tfp denotes total factor productivity.

4.2 Robustness checks

We perform a set of robustness checks. In the first step, capital structure is used as an additional control variable. The estimation result is only significant for tangible investments. The negative tangible coefficient implies that firms with high leverage are less financially constrained, which is counter-intuitive. A possible explanation for this result could be that highly leveraged firms have obtained loans and thereby performed all planned investment opportunities.

Furthermore, respondents to questionnaires may provide biased answers if they expect the results to have policy relevance. For example, the owners of firms may overemphasize the relevance of the financial constraints they face in the hopes of inducing the government to implement measures aimed at increasing the availability of financing. In order to mitigate this problem, an additional survey question is used in which each firm is asked if their company did not implement innovation projects due to lack of financial resources. We find a positive correlation between financial constraints and no implementation. Thus, there is correspondence between the hypothetical ideal test and real decisions.

5 Conclusions

This paper investigates the relationship between firm size and funding gaps using the Mannheim innovation panel. We use the approach developed by Hottenrott & Peters (2012), where high innovation capability is assumed to be the major driving force in the funding gap for innovation. However, we extend the approach of Hottenrott & Peters (2012) in several ways. We add an additional survey question in order to re-ensure consistency in the firms' responses to the question. Innovation investments are distinguished from tangible investments since, theoretically, innovation investments should be more financially constrained [7]. We add the 2014 wave of the survey to see changes over time; furthermore, we test whether financial constraints have an impact on firm productivity.

Our results show that the relationship between firm size and the funding gap is characterised by an inverse u-shape, where the middle-sized firms are the most constrained firms. There may be several explanations for this

[7] see Hall & Lerner (2010) for a theoretical overview.

result. As outlined in the theoretical framework, the demand for innovation funding depends on a firms' innovation capability; thus, the higher the innovation capability, the flatter the demand curve for innovation funding. Accordingly, medium-sized firms may have a higher innovation capability and thereby a higher funding need then their smaller counterparts. At the same time, medium-sized firms may also face higher marginal costs of capital in comparison to larger firms.

Furthermore, there seems to be a larger number of tangible investment opportunities that are not pursued, which could be an indication that tangible investment projects are more financially constrained. However, a possible explanation is that we have not controlled for the size of the investment project. Thus, tangible investments may, on average, be large and therefore require a larger amount of debt, thus affecting the probability of receiving debt funding. Finally, our results show that funding gaps for tangible investments reduce the productivity of firms. However, we do not find this adverse effect on productivity from funding gaps in innovation investments.

These results allows for better and sharper policy suggestions. Given the important role of SMEs in the German economy it is essential to identify different driving factors of financial constraints and which type of firms and investments that are most constrained. Thus, if innovation capability is in fact a driving force for financial constraints, then policy makers should target innovation capability itself. The concept of innovation capability was first introduced by Hottenrott & Peters (2012). Thus, the concept of innovation capability is rather unexplored. To the best of my knowledge this paper is the first one to relate innovation capability, financial constraint and firm size while also distinguishing between tangible and intangible investments. It is also the first paper that derives the financial constraint variable from innovation capability and relates it to a firms productivity. This paper makes an original contribution to the literature on financial constraint and innovation.

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