The Impact of Financial Markets on Innovation

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Chapter 1

Introduction

1.1 The importance of innovation and innovation financing

It is because of the influence of the works of Schumpeter (i.e. Schumpeter 1934; Schumpeter 1942) that the impact of technological progress on growth and social welfare has received increasing attention (e.g. Cohen 2010). However, it needed some time until the impact of exogenous (Solow 1957)[1] and endogenous (Romer 1986; Romer 1990)[2] technological change on growth was determined. Thus, today it is generally acknowledged that besides capital and labor (Harrod 1939; Domar 1946; Solow 1956), technological progress is an important driving force of economic growth (Aghion & Howitt 2009; Coe & Helpman 1995; Grossman & Helpman 1994; Romer 1986; Romer 1990).[3] One of the most important activities fostering technological change is the innovation activity of firms (Coe & Helpman 1995; Romer 1986; Romer 1990). At the level of firms, innovations as a result of R&D investments, for example, impact productivity, competitiveness and a firm's survival (e.g. Aw et al. 2007; Brown et al. 2009; Cefis & Marsili 2006). Consequently, the existing social as well as private returns imply incentives to invest in innovation.

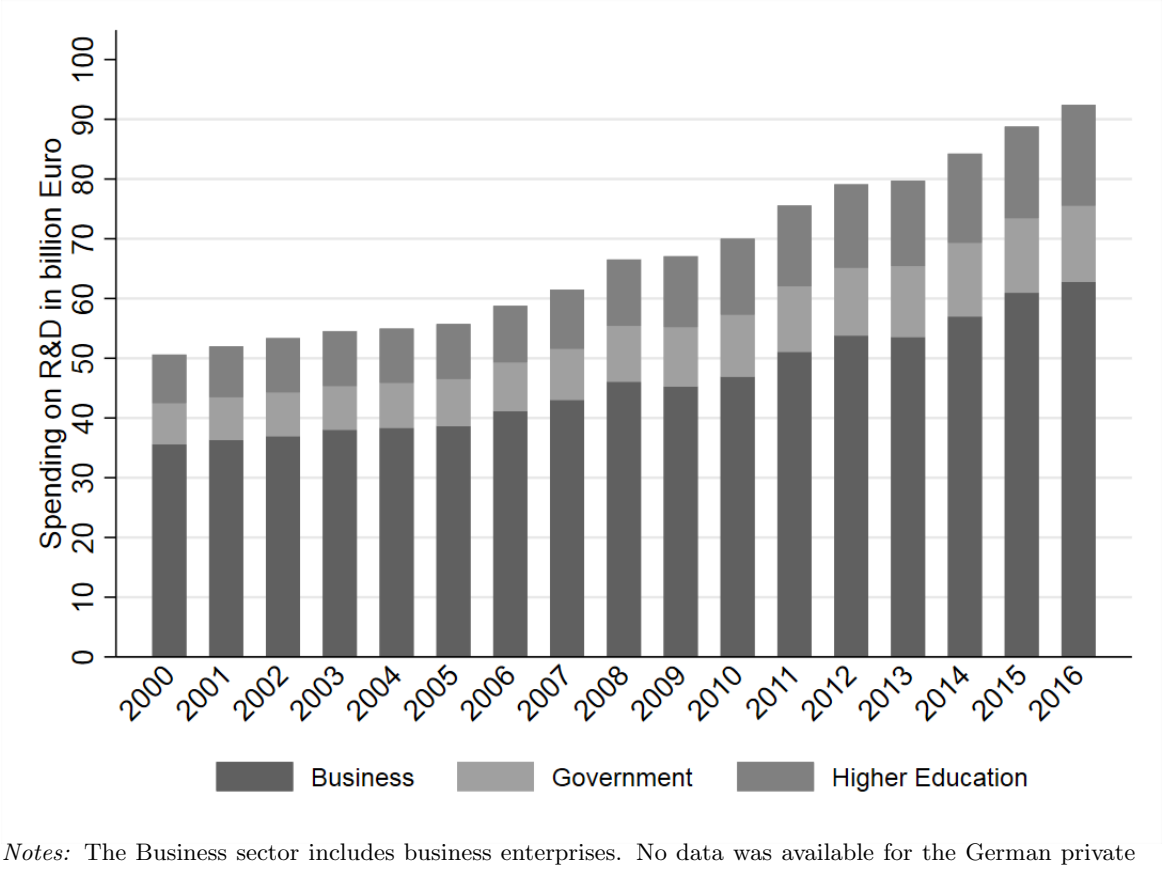
The economic view of the importance of innovation activities for economic growth is also shared by policy makers (e.g. European Commission 2010b). Thus, the 'Europe 2020' strategy, which aims at fostering economic growth, was enacted in 2010. It includes the 'Innovative Union' as one of seven flagship initiatives (European Commission 2010a; European Commission 2010b). The initiative is geared towards better conditions for innovation and R&D to increase public and private R&D investment to 3% of GDP by 2020 (European Commission 2010a; European Commission 2010b; European Council 2010; European Commission 2014). Figure 1.1 shows the R&D spending in billion Euro for the public and private sector in Germany. From the composition of Germany's R&D expenses, it becomes evident that private firms spend the largest share of R&D expenditures relative to the Government and Higher Education sectors. Moreover, the share of R&D expenses to GDP for Germany and the 28 EU members is converging to – but has not reached - the 3% target (OECD 2018). Thus, even if the social and private return from R&D is known, investments are below the policy target level and therefore likewise below the optimal social and private level.

[1] Robert M. Solow was awarded the Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel in 1987 "for his contributions to the theory of economic growth." (The Royal Swedish Academy of Sciences 2018a).

[2] Paul M. Romer and William D. Nordhaus were awarded the Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel in 2018 (The Royal Swedish Academy of Sciences 2018b). Paul M. Romer also received a joint prize "for integrating technological innovations into long-run macroeconomic analysis." (The Royal Swedish Academy of Sciences 2018b).

[3] The Solow (1956) growth model was extended in Solow (1957) by considering exogenous technological change as a shift factor for the production function.

Figure 1.1: Spending on R&D in billion Euro by sector in Germany



Notes: The Business sector includes business enterprises. No data was available for the German private non-profit sector.

Financing constraints are one of the most important reasons why investments in innovation are below the social and private optimal level (Aschhoff et al. 2013; European Commission 2010a; European Commission 2010b; Eurostat 2008; Hall 2002; Hall & Lerner 2010).[4] This effect of financing on innovation is mostly attributed to restrictions in internal means, but external funding also plays a significant role (Hall 2002; He & Tian 2018; Knudsen & Lien 2014).[5] Even though external financing can be obtained from different sources (e.g. bank debt, equity, venture capital), in bank dependent economies like Germany, bank financing is the most prevalent source (e.g. Agarwal & Elston 2001; Berger & Udell 1995; Boot 2000). It might be questioned why considering external financing is important as obtaining the necessary amount of firm financing might be no problem in a perfect capital market (Modigliani & Miller 1958). However, existent imperfections due to information asymmetry problems like adverse selection and moral hazard lead to re-

[4]See e.g. Aschhoff et al. (2013) who provide a summary of the results of the German part of the Community Innovation Survey (CIS). This survey also comprises an irregularly asked question concerning the factors which are considered obstacles to the innovation behavior of firms. Besides financing constraints, knowledge spillovers are an obstacle which is highly relevant for innovation (e.g. d'Aspremont & Jaquemin 1988; Griliches 1992; Jaffe 1986; Levin 1988).

[5]As financial preferences for firms vary, they likewise engage in a funding mixture of internal and external financing (Beck et al. 2008). According to the pecking order of financing, determined by Myers & Majluf (1984), firms prefer internal means (e.g. cash flow) over external sources (e.g. bank loans) and equity to finance investments.

stricted access to external financing (i.e. increased costs or restricted supply) (Holmstrom & Tirole 1997; Mishkin 1992; Stiglitz & Weiss 1981). Thus, in imperfect capital markets, a difference in the costs between internal and external funds exists (Fazzari et al. 1988, Leland & Pyle 1977).

The gap between the costs of internal and external financing is particularly large for firms conducting innovation and the financing of innovation related expenses (Hall 2002). The main argument for this hypothesis is that the financing of innovation is predominantly affected by asymmetric information between innovator and debt supplier (i.e. borrower and lender) (Hall 2002).[6] This is rooted in the difficult risk assessment of innovation projects (Arrow 1962) as well as large market uncertainties in the development and market stage (Leland & Pyle 1977). Moreover, the long duration from setting up the project to first payoffs (Czarnitzki & Hottenrot 2010) makes it difficult for innovators to serve their debt obligations in early project stages. Furthermore, innovation projects are not likely to serve the collateral requirements of debt suppliers like banks as they, for example, relate to low collateral (Hall 2002) and entail huge sunk costs (Alderson & Betker 1996). Additionally, even if a patent could serve as a quality signal (e.g. Francis et al. 2012; Hochberg et al. 2018; Hottenrott et al. 2016), the innovator might not be willing to provide valuable information about his project quality when sourcing external financing (Bhattacharya & Ritter 1983) or does not even patent valuable inventions (Hall et al. 2014). Thus, these characteristics stand in contrast to the requirements for obtaining debt by banks.

Even if the importance of financial intermediaries for innovation and growth had already been highlighted by Schumpeter (1934)[7], the relation between bank financing and innovation remains widely discussed in the literature (e.g. Hall 2002; Hall & Lerner 2010; Kerr & Nanda 2015; He & Tian 2018). Consequently, this thesis focuses on the impact of financial markets on innovation. On the one hand, this includes the analysis of the sensitivity of innovative firms to restrictions in external financing. On the other hand, the reaction of innovation activities to changes in the supply of external financing is investigated. In that respect, in particular the lack of access to and supply of bank financing in the recent financial crisis is being used as source of underinvestment in innovation.

[6] See e.g. Hall & Lerner (2010) for an overview.

[7] See Ülgen (2015) for an extensive discussion of the relation between innovation, growth and finance. Furthermore empirical works show that access to external financing is important for growth (e.g. King & Levine 1993; Musso & Schiavo 2008; Rajan & Zingales 1998).

1.2 Identification of the effect of external financing on innovation

1.2.1 Identification of financing constraints for innovation

Even if it is argued that financing constraints and firm behavior are related to some extent, the identification of financing constraints is not trivial. This identification issue could be approached from two perspectives: The firm side or the supply side of external financing (e.g. banks). Early works relied on a firm's cash-flow as a measure for financing constraints (e.g. Carpenter et al. 1998; Fazzari et al. 1988; Himmelberg & Petersen 1994). Despite this indicator receiving great attention and still being used today (e.g. Brown et al. 2012), it remains under discussion (e.g. Kaplan & Zingales 1997; Kaplan & Zingales 2000; Carreira & Silva (2010); Hadlock & Pierce 2010).[8]

Following this debate, several additional indicators have been established to measure financing constraints (see e.g. Hadlock & Pierce 2010; Lamont et al. 2001; Whited & Wu 2006)[9]. Nevertheless, it is argued that these suffer from limitations as well (Carreira & Silva 2010; Hadlock & Pierce 2010). As a result of this debate, Carreira & Silva (2010) propose using classification measures based on, for example, firm self-evaluations, leverage, size, age and credit ratings. Chapter 5 of this thesis takes up this discussion and utilizes a firm's credit rating as an indicator of a firm's financing constraints. This measure offers information about the financial strength of firms (Peters et al. 2017) and about their access to external financing (Czarnitzki & Hottenrott 2011a; Czarnitzki & Hottenrott 2011b). Also, other firm characteristics such as innovativeness are determinants of a firm's ability to access external financing (e.g. Freel 2007; Mina et al. 2013) and of its financial strength (e.g. Czarnitzki & Kraft 2007). Chapter 2 of this thesis utilizes a firm's innovator status to characterize those firms facing larger difficulties in accessing external financing.

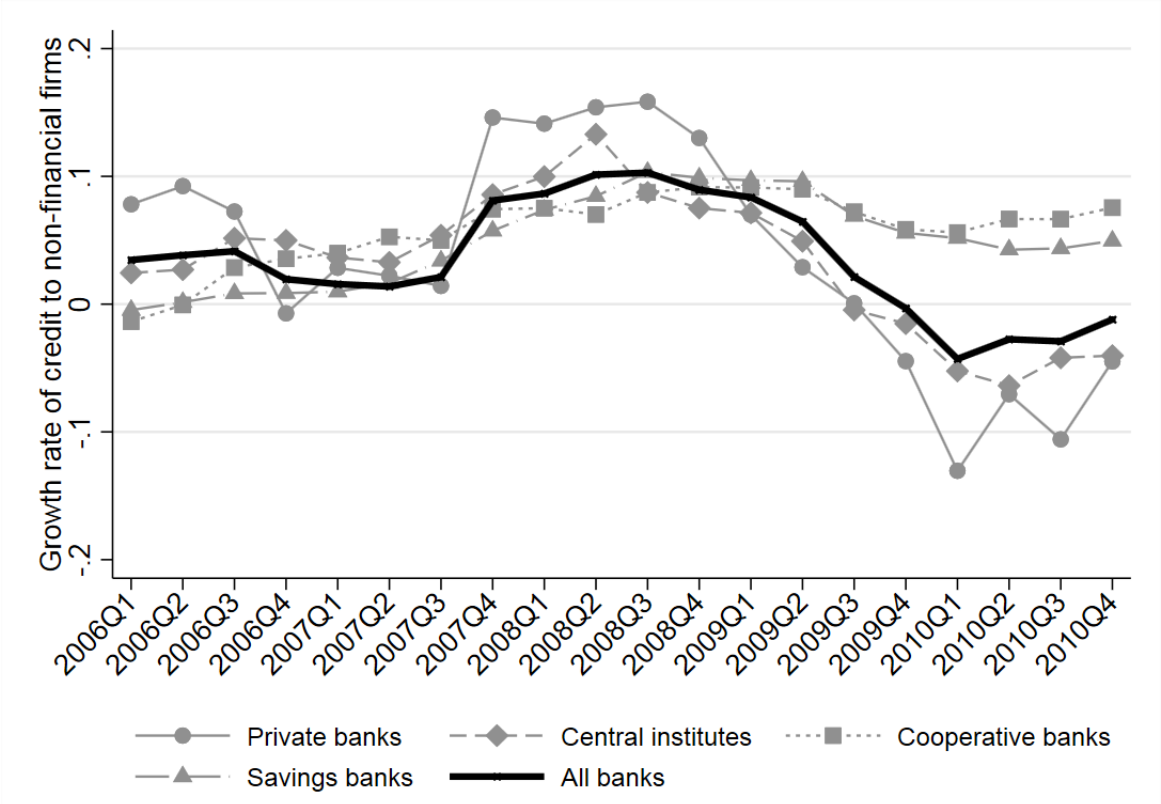
Compared to the determination of financing constraints from a firm's perspective, identifying financing constraints directly from the supply side is even more difficult. The ideal identification approach would constitute reaction to a shock which affects the supply side but not the demand side of external financing. In bank dependent systems like Germany this would appear as a negative shock to banks which affects the ability of the financial system to efficiently channel funds (Ehrmann & Worms 2004; Kahle & Stulz 2013; Mishkin 1992; Upper & Worms 2004). Such a shock would result in negative effects on the real sector (e.g. Holmstrom & Tirole 1997).

[8] See Carreira & Silva (2010) for an overview of studies which utilize the cash-flow sensitivity as an indicator for financing constraints.

[9] Examples include the Kaplan and Zingales index (Lamont et al. 2001), the Whited-Wu index (Whited & Wu 2006) and the Size-Age index (Hadlock & Pierce 2010). These indicators are merely applied to investigate the effect of financing constraints on capital investment.

The chapters in this thesis (Chapter 2, 3, 4, 5) utilize the global financial crisis of 2008/2009 for the identification of financing constraints from the supply side. The burst of the subprime-mortgage bubble resulted in severe liquidity problems for banks which had invested in speculative assets (Popov & Rocholl 2018; Puri et al. 2011). Besides banks in the US, German banks also experienced large losses (Dietrich & Vollmer 2012). Additionally, banks were affected by huge uncertainties in the financial system which arose in the aftermath of the collapse of Lehman Brothers in late 2008 (e.g. Acharya & Skeie 2011; Ashcraft et al. 2011; Acharya & Merrouche 2012). Because of this turbulence on the financial markets, banks reduced their credit supply (e.g. Ivashina & Scharfstein 2010) which was also observable in Germany (Bundesbank 2009; Hallerberg & Markgraf 2018; Meriläinen 2016; Popov & Rocholl 2018; Puri et al. 2011). Figure 1.2 shows that the overall credit growth rate (bold line) started to decline in late 2008 and became negative at the end of 2009. It shows how this huge shock to the banking system led to spillovers in the real sector (e.g. Huber 2018). Chapters 2 and 5 of this thesis use the general crisis induced decline in credit volume and credit conditions to indicate times of difficulty accessing external financing for firms dependent on their characteristics. In that respect the innovator status (Chapter 2) and the firm's credit rating (Chapter 5) are used to identify firms with larger difficulties accessing external financing.

Figure 1.2: Credit supply by bank type from 2006 to 2010



Notes: The figure shows the quarterly growth rate of loans to German enterprises and self-employed persons compared to the same quarter in the previous year. The category 'All banks' includes Mortgage banks, branches of foreign banks and banks with special functions. Source: Bundesbank (author's own calculations).

As shown in Figure 1.2, the negative development of the credit supply growth rate holds in particular for private banks as well as the head institutions of the cooperative bank and savings bank sectors.[10] Conversely, the growth rate declined only slightly for cooperative and savings banks but remained positive. And even among the group of savings banks, a heterogeneous credit development was observable during the financing crisis (e.g. Puri et al. 2011). Thus, even if the reduction credit supply by banks to firms and households is evident, the decrease in lending was not homogeneous across banks. The disruption on the interbank market during the recent financial crisis is of particular interest as this market serves an important role for the redistribution of liquidity among banks (Craig & Von Peter 2014; Bräuning & Fecht 2016).[11] Accordingly, banks reduced lending to non-financial firms in the financial crisis dependent on their reliance on the interbank market for the refinancing of loans (e.g. Bundesbank 2009; Bundesbank 2016; Cingano et al. 2016; Iyer et al. 2014). Thus, Chapter 3 and 4 of this thesis apply indicators (i.e. the interbank market borrowing to assets ratio) for the exposure to the interbank market disruption in order to identify external financing constraints of firms. In that respect Chapter 4 in particular shows how the effect of the interbank market disruptions was transmitted by the bank credit supply channel to firms.

Moreover, banks' balance sheet strength plays an important role in banks' transmission of the crisis induced shock to the real sector (Kapan & Minoiu 2018). In that respect, bank capital reflects banks' own funds (Adrian et al. 2018), the ability to absorb shocks (Diamond & Rajan 2000; Mingo 1975), agency costs of borrowing (Holmstrom & Tirole 1997) and the costs of funding (Mingo 1975). Regarding the recent financial crisis, it is shown how banks with a weak bank balance sheet in terms of capital and liquidity had a lower ability to absorb the shock and so saw their credit supply reduced as a result (Adrian et al. 2018; Beltratti & Stulz 2012; Berger & Bouwman 2013; Jiménez et al. 2012; Kapan & Minoiu 2018). Thus, bank capital is a suitable indicator to identify banks which are adjusting their credit supply negatively and applying tighter credit conditions. Consequently, Chapter 5 of this thesis uses indicators for the capitalization of banks to account for constraints of a firm's main bank.

1.2.2 The measurement of innovation activities

In addition to the identification problem for financing constraints, it could be questioned how to best proxy corporate innovation activities (He & Tian 2018; Kerr & Nanda 2015). The choice of a particular measure is especially important when investigating the relation between financing and innovation (He & Tian 2018; Kerr & Nanda 2015). In that respect, patents and patent citations are frequently used output-based metrics for innova-

[10] These bank types are, among other characteristics, riskier and more dependent on financial markets for loan refinancing than cooperative and savings banks (e.g. Ferri et al. 2014; Lang & Welzel 1996).

[11] See e.g. Chor & Manova (2012) who argue that the interbank rate serves as a proxy for the countries' costs of capital.

tion (Trajtenberg 1990).[12] This is rooted not least in the fact that patents are informative concerning a firm's innovation strategy (Kerr & Nanda 2015). However, measures based on patent data are not free from limitations (Lerner & Seru 2017). When investigating the relationship between financing and innovation, a major problem might be the time span from the start of the innovation project to the patent application to the granted patent. Thus, a heterogeneous lag between a shock to financing and changes in patent application or granted patents is to be expected. Moreover, there are indeed a lot of innovations which are not patented (i.e. trade secrets) at all (Hall et al. 2014). This makes it quite difficult to measure the impact of a financial shock on innovation. Nevertheless, these indicators might be informative concerning the persistence of financial shock induced changes to firms (e.g. Huber 2018) or long-term strategic adjustments (e.g. Nanda & Nicholas 2014). Consequently, patent-based indicators might not be the first and best choice when utilizing a shock such as the recent financial crisis to identify the direct relation between bank financing and innovation.

Besides patents, R&D and other innovation related expenditures are frequently used as input-based measures to proxy corporate innovation activities (He & Tian 2018). One advantage over patent information is the rather direct reaction to changes in organizational behavior. Chapter 5 of this thesis utilizes firms' R&D expenditures as identifiers for firm innovation to investigate direct firm reactions to firm and bank financing constraints. To investigate the relation between external financing constraints and innovation, Chapter 3 utilizes innovation expenditures of firms as a measure for firm innovation. A clear advantage of utilizing these is the available information regarding their components. Accordingly, Chapter 3 breaks down innovation expenditures in investments in innovation and current innovation expenditures. While the latter is rather inflexible, investments in innovation might be highly reactive to changes in financing. Thus, investigating the effect on these components yields further insights in the innovation adjustment processes of firms that are dependent on external financing constraints. Though innovation related expenditures are input-measures which react more direct to changes in the organization, they are not free of limitations (e.g. no information about the innovation strategy, measurement errors, no information on additional inputs for innovation) (He & Tian 2018). Thus, innovation expenditure related measures can track changes concerning the input in innovation but not concerning the changes in the innovation department or innovation strategy.

A measure which might overcome some issues inherent in both previously mentioned indicators (i.e. input and output) are survey-based measures of innovation. These have been discussed for some time (e.g. Archibugi & Planta 1996) and are widely applied in the innovation financing context (e.g. Ayyagari et al. 2011; Mohnen et al. 2008; Savignac 2008). It should, however, be noted that innovation survey data also has limitations (e.g. sparse exact information on the introduced innovation) (e.g Archibugi & Planta 1996).

[12] See e.g. Hall & Harhoff (2012) for an overview of studies which use patents as measure for innovation.

Thus, it might be questionable how helpful innovation survey information indicators can be when determining the consequences of a financial crisis on the innovation behavior of firms. Chapter 4 of this thesis overcomes this problem by using a special set of survey questions that asked firms about the impact of the financial crisis on firm innovation. These yield details on the direct innovation adjustments of firms as a response to the crisis (e.g. innovation reduction due to funding shortages, initiation of additional innovation, reallocation of human resources to innovation). Moreover, the utilized innovation information from the survey helps to determine whether a firm adjusts its innovation strategy in response to a crisis. Consequently, in this thesis detailed information derived from innovation survey data allows an unprecedented, detailed picture to be drawn of the innovation behavior of firms during the crisis (Chapter 4).

1.3 Chapter Overview

The **second chapter**[13] of this thesis investigates the impact of the financial crisis on capital investments in innovative firms. It is generally acknowledged that the characteristics of innovative firms lead to larger problems in accessing external financing like bank loans in the recent financial crisis (e.g. Lee et al. 2015; North et al. 2013). However, outcome-based evidence on the impact of financing constraints of innovative firms is so far lacking. In that respect, capital investments are particularly interesting to analyse as they are usually financed by a mixture of internal and external means (Beck et al. 2008). Thus, empirical studies show that physical capital investments are indeed sensitive to external financing (e.g. Chava & Purnanandam 2011; Czarnitzki & Hottenrott 2011b; Fazzari et al. 1988; Lemmon & Roberts 2010; Whited 1992; Zarutskie 2006). This is also evident from the recent financial crsis (e.g. Almeida et al. 2012; Campello et al. 2010; Duchin et al. 2010; Vermoesen et al. 2013).

In that context Chapter 2 questions how firms with different combinations of innovator status and usage of external financing adjusted their investment in the financial crisis. If the above described problems to obtain debt were prevalent for innovative firms, it could be assumed that they reduced their investment to a larger extend than non-innovators. Similarly, firms dependent on external financing, like bank loans, are also likely to have reduced their investments to a larger extent. Using the IAB establishment panel allows a determination to be made of the innovator and external financing user status of firms. Utilizing the financial crisis as an exogenous shock allows the application of difference-in-differences specifications with multiple treatment groups. This specification aims to test for changes in the investment behavior of the specific groups in reference to the group

[13]The chapter is entitled "The impact of the financial crisis on capital investments in innovative firms". A previous version of this chapter has been published as: Giebel, M. & Kraft, K. (2019). The impact of the financial crisis on capital investments in innovative firms. *Industrial and Corporate Change*, 28(5), 1079-1099.

of firms which are neither innovative nor external financing users. Moreover, it allows a detangling of whether the investment behavior is different for the formed groups from the innovator and external financing indicators.

Another question which is answered by this chapter is whether firms which used equity financing displayed a different investment behavior during the crisis. This question is of particular interest as equity financing has been found to be beneficial for innovation (e.g. Carpenter & Petersen 2002; Magri 2009).[14] However, it is shown that the substitution of scarce financing sources is difficult in times of stress on financial markets (Holmstrom & Tirole 1997; Kahle & Stulz 2013). Thus, the chapter also aims to determine whether firms which utilize equity financing as an additional financing source experienced different changes in investment expenditures during the crisis. For this purpose, the previous specification is extended so that equity financing is taken into account. This allows one to test, (i) whether the effect for firms using equity financing is different from that of the control group (i.e. non-innovative firms using no external financing) and (ii) whether the effect is different among the various treatment groups.

The **third chapter**[15] of the thesis investigates the impact of external financing constraints on the innovation expenditures of firms. It is argued that innovation is financed largely by internal sources and not suitable to be financed by external means such as bank loans (e.g. Hall & Lerner 2010).[16] Nevertheless, studies have found an association between the access of external financing on R&D (Czarnitzki & Hottenrott 2011a; Czarnitzki & Hottenrott 2011b) and changes in the bank system and innovation (e.g. Alessandrini et al. 2010; Amore et al. 2013; Benfratello et al. 2008; Chava et al. 2013; Cornaggia et al. 2015; Hsu et al. 2014; Nanda & Nicholas 2014).[17] Thus, it remains debatable whether and how innovation related expenditures are affected by external financing like bank loans (Brown et al. 2012; Hall & Lerner 2010; Kerr & Nanda 2015). Consequently, the empirical study in Chapter 3 offers a major contribution to the debate on the relation between bank financing and innovation.

The variation induced by the financial crisis on the banking sector delivers a fruitful opportunity to identify external financing constraints. For this purpose, the fact that the disruptions on the interbank market in the recent financial crisis led to bank lending reductions to non-financial firms is utilized (e.g. Cingano et al. 2016; Iyer et al. 2014). Thus, the degree of reliance of a firm's main bank on the interbank market for loan refinancing

[14] The use of equity as another opportunity is not as frequently undertaken in Germany as bank borrowing (Engel & Keilbach 2007; Gottschalk & Licht 2013).

[15] The chapter is entitled "External financing constraints and firm innovation". A previous version of this chapter has been published as: Giebel, M. & Kraft, K. (2019). External financing constraints and firm innovation. *Journal of Industrial Economics*, 67(1), 91-126.

[16] Empirical evidence exists which shows that there is no (e.g. O'brien 2003) or a negative correlation between leverage and R&D (e.g. Bhagat & Welch 1995; Friend & Lang 1988).

[17] See Knudsen & Lien (2014) for a discussion of how external financing could affect R&D investment directly due to a denial of credit or indirectly by i.e. scarce unused borrowing capacities or large adjustment costs.

purposes is crucial to identify a firm's restrictions for obtaining external means of funding. This is rooted in the expectation that firms related to a bank with higher interbank market reliance are more exposed to a negative credit supply shock. Consequently, a firm's main bank's interbank market borrowing to asset ratio is applied as a continuous treatment indicator in a difference-in-differences approach. Making use of this specification allows a determination to be made of the impact of external financing constraints on the innovation expenditure of firms.

Compared to filed or granted patents, an input related measure like innovation expenditure reacts without any lag. Thus, the idea is that if there is any sensitivity of innovation to external financing, it will be reflected by the change in innovation expenditure. In addition, the chapter aims to determine which aspect of innovation expenditure is affected to a stronger degree by the turbulence on financial markets. For this purpose, innovation expenditures are distinguished between the rather inflexible part of current innovation expenditures and the likely more flexible investments in innovation. It is to be expected that these react to some extent heterogeneously to the changes in available external financing for firms.

In addition to the expenditures for innovation, marketing expenditures are also considered. It has been shown that marketing expenditures are related to a firm's systemic risk (McAlister et al. 2007) and the availability of firm financing (e.g. Fischer & Himme 2017; Singh et al. 2005). In that respect, it could be expected that marketing expenditures react differently than innovation expenditures to any reduction in bank credit supply. For marketing expenditures, it is however questionable whether and how they react to changes in the financial health of a firm. Thus, the chapter also tests whether these expenditures react to external financing constraints.

Chapter four[18] of the thesis exploits the bank credit supply channel to use it as a determinant of a firm's innovation behavior in the financial crisis. It has been shown how turbulence on the financial markets spilled over to the real economy due to the bank credit supply channel (e.g. Balduzzi et al. 2018; Bentolila et al. 2017; Chodorow-Reich 2014; Cingano et al. 2016; Dwenger et al. 2018; Iyer et al. 2014; Popov & Rocholl 2018). Moreover, studies exist which focus on the innovation related changes (i.e. increase or decrease of innovation) of firms in the financial crisis dependent on various firm characteristics. These are, for example, past experiences with recessions (Amore 2015), the pre-crisis innovativeness of firms (Archibugi et al. 2013a; Archibugi et al. 2013b), their size, age and use of public or private financing (Paunov 2012), as well as access to subsidies (Hud & Hussinger 2015). Nevertheless, evidence pointing to the impact of the bank credit supply channel on innovation behavior in the financial crisis is absent. Moreover, detailed insight into the innovation behavior of firms is not considered, as measures like

[18]The fourth chapter of this thesis is entitled "Bank credit supply and firm innovation behavior in the financial crisis". A previous version of this chapter has been published as ZEW Discussion Paper: Giebel, M. & K. Kraft (2018). Bank credit supply and firm innovation. *ZEW Discussion Paper*, 18-011.

innovation related expenditures and patents have limitations in their informative content (He & Tian 2018).

To fill this existing gap, survey-based measures are applied which reflect both the immediate innovation adjustments of firms in 2009 and the emphasis on specific firm innovation strategies to cope with the consequences of the crisis. As the fourth chapter aims to examine the bank credit supply channel, the interbank market reliance of the firm's main bank as supply side instruments for bank lending is applied. Utilizing this instrumental variable estimation approach allows credit demand and supply effects to be detangled as well circumventing possible feedback effects. To determine the immediate innovation adjustment, the following changes are considered: the reduction of current innovation activities due to funding shortages, the initiation of additional product or process innovation and the reallocation of human resources to innovation.

Additionally, the chapter aims to explain whether the effect of the bank credit supply reduction depends on the availability of internal means. This is particularly important as works like Holmstrom & Tirole (1997) have shown that firms suffer in particular from a shock to banks when internal means are scarce. This is in line with the theoretical finding that innovation is financed mostly by internal means (Hall 2002). Moreover, empirical works like Aghion et al. (2012) show that a denial of credit supply in an economic downturn leads to a reduction in R&D which results in pro-cyclical innovation behavior. Thus, the effect of credit supply on innovation dependent on the available internal funds in the financial crisis is investigated. This yields further insights into the financing patterns of innovation and the cyclicality of innovation.

Concerning strategic decisions, a determination is made as to whether a firm utilized innovation related strategies to cope with the consequences of the crisis. In that respect, strategies with respect to costs reductions, the exploration of existing new markets or the exploitation of existing markets are considered. The innovation strategy is determined before the innovation projects started and therefore as the base of future innovation activities. Thus, the innovation strategy is essential for firm growth and survival (e.g. Guan et al. 2009). Consequently, it is of general interest to know whether a shock to external financing also leads a firm to adopt a specific innovation strategy to cope with adverse economic conditions.

The empirical analysis in **Chapter five**[19] determines the impact of firm financing constraints on R&D by accounting for the stress on financial markets and resulting constraints from the firm's main bank. It is generally acknowledged that R&D reacts sensitively to firm financing constraints in terms of cash flow (e.g. Bond et al. 2005; Brown et al. 2009; Brown et al. 2012; Hall 1992; Hall et al. 2001; Harhoff 1998; Himmelberg & Petersen 1994; Mulkay et al. 2001). Nevertheless, this indicator remains under discussion (Carreira

[19]This chapter is entitled "The sensitivity of R&D to financing constraints of firms as well as of their banks" and joined work with Kornelius Kraft.

& Silva 2010; Kaplan & Zingales 1997; Kaplan & Zingales 2000). Thus, in Chapter 5 a firm's credit rating index is applied as an indicator of a firm's financing constraints.[20] This measure gives information about the financial strength of firms as well as their access to external financing (e.g. Czarnitzki & Hottenrott 2011a; Czarnitzki & Hottenrott 2011b, Peters et al. 2017).

Utilizing this indicator, the fifth chapter aims to test whether the sensitivity of a firm's R&D to its credit rating depends on bank financing constraints. Existing studies which have investigated the R&D to cash flow sensitivity dependent on external financing focus on equity or venture capital (e.g. Brown et al. 2009; Brown et al. 2012). Thus, it remains open how a firm's financing constraints affect R&D expenses dependent in turn on bank financing constraints. The chapter fills this gap by providing novel evidence when answering two questions: First, it determines whether the sensitivity of R&D to firm constraints changes in crisis periods and whether this effect remains persistent. Thus, in addition to a period (2002-2006) before the financial crisis and the introduction of the Basel II guidelines, a crisis period (2007-2009) and a post-crisis period (2010-2012) are used. This allows an identification to be made of changes in the effects of financing constraints on R&D in a difference-in-differences context. Moreover, the applied specification yields insights into whether the effect is persistent over time.

Second, in the fifth chapter it is determined whether the impact of firm constraints on R&D depends on the financial strength of the firm's main bank. Banks with a weak bank balance sheet in terms of capital and liquidity had a lower ability to absorb the crisis induced shock and reduced their credit supply as a result (Adrian et al. 2018; Beltratti & Stulz 2012; Berger & Bouwman 2013; Jiménez et al. 2012; Kapan & Minoiu 2018). Thus, it remains questionable, whether being related to a bank with higher financial strength attenuates firm constraints to some extent. On the opposite side, being related to a bank of low strength might make firm constraints more severe. Consequently, the sensitivity of R&D to firm financing constraints is analyzed for firms related to both high and low capitalized banks.

Third, subsidies are considered as an additional financing source. It is well known that subsidies affect R&D expenses (e.g. Almus & Czarnitzki 2003; Becker 2015; Howell 2017; Zúñiga-Vicente et al. 2014) which was also observed in the recent financial crisis (e.g. Brautzsch et al. 2015; Hud & Hussinger 2015). However, it continues to be debated in the literature whether there is an additionality of R&D subsidies or a crowding out of existing expenditures (e.g. Busom 2000; Hud & Hussinger 2015). Even while this is debated, studies have argued and shown that receiving subsidies might mitigate the financing constraints of firms (e.g. Hall et al. 2016; Hyytinen & Toivanen 2005; Takalo & Tanayama 2010). In that respect, in a first step the chapter analyzes whether receiving

[20] See e.g. Czarnitzki & Hottenrott (2011a); Czarnitzki & Hottenrott (2011b), Peters et al. (2017) for papers which also use the firm's credit rating index as an indicator for financing constraints.

subsidies affects firm financing constraints. Next, light is shed on the question of whether the sensitivity of R&D to firm and bank constraints differs for firms which are classified as subsidy recipients and those who do not receive subsidies. This analysis reveals whether subsidies mitigate the financing constraints of firms and banks.

The remainder of the thesis is structured as follows. Chapter 6 deals with a summary of the main findings in chapters two to five. Moreover, the sixth chapter will highlight the contributions to the literature as well as implications which can be drawn from this thesis for firms, banks and policy makers.

Chapter 2

The impact of the financial crisis on capital investments in innovative firms

Co-authored with Kornelius Kraft

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2.1 Introduction

Capital investment is associated with effective demand, employment and economic growth (Domar 1946; Harrod 1939; Keynes 1936; Solow 1956). On the firm level, capital investments determine, for example, the allocation of financial resources, the market to operate in and the success of operations (Hay & Morris 1991). Thus, investments play a central role with respect to firm development, growth and survival (Hay & Morris 1991). Even if the social and private return to investment is known, firms might realize an investment level below the optimal point due to internal or external financing constraints (e.g. Hall 2002). These constraints in terms of access to external finance stem from capital market imperfections due to agency conflicts, moral hazard and adverse selection (e.g. Holmstrom & Tirole 1997; Stiglitz & Weiss 1981).

Furthermore, costs and availability of funds are affected by firms' investment decisions and growth strategy (Nickell 1978). Thus, problems of accessing external financing might become more severe if firms engage in risky activities like innovation in order to facilitate development and growth. These risks stem from uncertainties concerning the success of the project, market acceptance and the attainable revenue stream. In particular, the asymmetric information problem between innovator and bank as money lender leads to major difficulties concerning access to financing from external sources (Hall 2002). Thus, as empirical studies show, innovative firms are more likely to be affected by external financing constraints than non-innovative firms (Freel 2007; Hall 2002; Mina et al. 2013). Moreover, the intensity of constraints for innovative firms increases with the innovation's degree of novelty to the market (Czarnitzki & Hottenrott 2011a).

We investigate whether innovativeness and external financing constraints are independent of each other or whether innovative firms realize greater problems when it comes to investment funding. We consider the financial crisis as an exogenous source of strong and unexpected distortion of financial markets. The financial sector was hit by a collapse of the interbank market and partly by losses related to portfolios of structured finance products and so-called toxic assets. The consequence was a liquidity crunch which was passed on to the corporate customers (and other customers) in the form of reduced lending (e.g. Cingano et al. 2016; Iyer et al. 2014). This eases the identification of a causal relation to the real sector. Hence, the given setting offers the opportunity to investigate the relevance of debts (and reduced lending supply) for investment. With a shortage of capital, banks become more selective about the financing of projects, and it is quite probable that innovators suffered as a result. Thus, we analyze two hypotheses: First, whether innovative firms changed their investments in capital goods by a larger degree than their non-innovative counterparts who were also relying on external financing. Second, we determine whether innovative firms using external finance changed investments to a similar degree as innovative firms using no external sources.

The empirical analysis is based on data from the IAB establishment panel and includes the waves 2004 to 2012.[1] The IAB establishment panel samples firms from the whole of Germany and covers several establishment characteristics and questions related to innovation and capital investments. The panel character allows us to compare changes in outcome, such as investments in capital goods, for both innovative with non-innovative firms over time. We are able to identify innovative firms (i.e. firms with riskier business models) that used external finance prior to the crisis in order to finance their investment activities. In our study a firm is defined as innovative if it has introduced a novel product to the market[2] in the three years 2005 to 2007 prior to the crisis. It might be argued that the innovator variable might not reflect the innovative activity in the crisis period. Nevertheless, this approach has several advantages. We avoid sampling firms in the treatment group that are solely successful innovators during the crisis period. Adding these firms to the treatment group would bias our results as these firms might be successful due to crisis-induced reasons. Next, we would have to account for the firm-specific differences of innovators in the crisis and those who were innovative in normal times. These two types might be different. Difficulties experienced by innovative firms in accessing external finance might have intensified during the financial crisis. Thus, we conduct (variants of) difference-in-differences estimations with multiple treatment groups to compare the impact on capital investments for innovators using external finance and those who do not.

Our analysis implies that innovative firms and those firms using external financing reduce their investment expenditures during the financial crisis. Moreover, we find that the effect differs when considering comparisons among the groups. For our first hypothesis, we find that innovative firms indeed reduce their investments by a larger extent compared to non-innovators among the firms utilizing external financing. Considering the second hypothesis, our empirical analysis implies that among the innovative firms, those using external sources in terms of bank financing reduce their investment spending to a greater degree. Investigation of the effect heterogeneity reveals that the crisis effect lasts longest for the group of innovative firms using external financing. Tests for the common trend assumption of the difference-in-differences approach indicate that the assumption holds. Moreover, we consider the possibility that demand side-effects are driving the investment reductions. The empirical results show that the demand component plays a role but does not dominate the effect of the innovation and external financing interactions. Last, our analysis reveals that external financing using equity does not play a significant role in the investment reduction of firms. However, the effect of the reduction is also prevalent for firms using both bank financing and equity financing. Thus, our main findings are robust to the aforementioned variety of changes.

[1] The data was collected by the Institute for Employment Research (IAB), located in Nuremberg, Germany.

[2] cf. Freel (2007), Mina et al. (2013) and Lee et al. (2015) for a similar procedure.

We contribute to the literature in several ways. Although other studies have investigated the effect of credit constraints on investments in the recent financial crisis (e.g. Almeida et al. 2012; Campello et al. 2010; Duchin et al. 2010; Vermoesen et al. 2013), this is the first study, to our knowledge, analyzing whether innovators' investment plans are affected more by the crisis than others. Moreover, our study adds results for the investment behavior of firms with riskier business models and dependence on external financing in a bank-based economy. Furthermore, we contribute to a strand of literature that investigates the effect of the financial crisis on the financing of innovative firms (e.g. Lee et al. 2015; North et al. 2013). Their findings imply that innovative as well as non-innovative firms faced weakened access to external financing in the financial crisis. However, innovators have a higher risk of absolute credit rationing (i.e. no access to external financing). By investigating investments as outcome of the financing process, we show that innovative firms suffer more than their non-innovative counterparts. We conclude that this is rooted in the risky and uncertain nature of innovation, which leads to problems in accessing external financing.

Our results imply that the shock to the bank system is especially problematic in a bank-based economy, as it is not possible to substitute external financing sources, particularly for riskier firms. In that respect, the availability of funding from other sources (e.g. equity financing) has to be improved such that firms might be able to substitute their financing source. In addition, our study implies generally that regulatory actions must be taken to strengthen the supply of capital by banks in times of distress on financial markets. Moreover, we can infer from our findings that a counter-cyclical funding is required for innovative firms, as their financing problems might have intensified during the crisis.

Our contribution is structured as follows: Theoretical as well as empirical results concerning innovative firms, external financing and investments are discussed in Section 2.2. Section 2.3 covers a description of the data and variables used for the empirical analysis in Section 2.4. In the penultimate Section 2.4, we present the results of our empirical analysis and further robustness tests. Concluding remarks are made in Section 2.5.

2.2 The effect of the bank lending shock on investment by innovative firms

The collapse of Lehman Brothers in late 2008 marks one of the most important events of the recent financial crisis. The crisis impacted on banks that relied on the interbank market[3] and also if they themselves had risky assets in their portfolio that dramatically

[3]Since the start of the financial crisis in 2007 interbank interest rates increased, and reached their maximum in October 2008, immediately after the collapse of Lehman Brothers. The insolvency of the Lehman Brothers bank in September 2008 led to a practical breakdown of the interbank market. Above all, it was those banks that largely relied on this way of refinancing that experienced problems, which they passed on to their corporate customers.

lost in value. Such unfortunate circumstances reduced the banks' resources for lending. In addition to these increased obstacles to debt financing during and after the crisis, banks implemented a stricter risk management. This was induced by the external requirements of the Basel II accord (Basel Committee on Banking Supervision 2006), but was also the consequence of tightened risk assessment by the banks to avoid losses from defaults following the lessons learned from the crisis (Bundesbank 2016).

In addition to theoretical investigations[4], empirical studies present evidence that lending activities by banks were indeed reduced because of the crisis (Ivashina & Scharfstein 2010, Brei & Schclarek 2013, Meriläinen 2016). Analyzing the impact of interbank market funding, Iyer et al. (2014) for the U.S. as well as Cingano et al. (2016) in the case of Italy show that the breakdown of the interbank market led to a reduction in firm credit by banks that relied heavily on this source to finance their lending activities. For Germany, growth in lending by banks was also reduced by about 5% from 3.8% to -1.3% between July 2008 and March 2010 (Bundesbank 2009; Bundesbank 2011; IMF 2016). Lending to non-financial firms contracted in particular (Bundesbank 2009). The contribution of loans to non-financial firms to credit growth began to decline at the end of 2008 and reached its minimum of -1.2% at the end of 2009 (Bundesbank 2011). Moreover, Puri et al. (2011) analyze the lending behavior of German public savings banks in the recent financial crisis. Their results indicate that especially those public savings banks that were controlled by an affected Landesbank reduced their lending as a result of the recent financial crisis.

Capital market imperfections due to asymmetric information and credit rationing concerning investments (Stiglitz & Weiss 1981; Holmstrom & Tirole 1997) likewise grew more severe during the financial crisis.[5] Consequently, costs of funds and the availability of external financing for investments are affected negatively by this bank lending shock. In addition, Kahle & Stulz (2013) point out that a negative bank lending shock leads to less borrowing and probably to firms trying to find substitutes like equity. However, it is quite likely that such sources are also reduced in times of financial crisis. Thus, firms that are dependent on bank borrowing likewise reduce their investments compared to firms that do not rely on this source of financing.[6]

Empirical evidence points to a reduction in capital investment behavior due to financial constraints during the crisis (Almeida et al. 2012; Campello et al. 2010; Cingano et al. 2016; Duchin et al. 2010; Vermoesen et al. 2013). Comparing constrained and unconstrained firms, Campello et al. (2010) present empirical evidence that constrained firms are more likely to reduce investments and technology expenditures because of the crisis. Duchin

[4]The theoretical investigation by Brei & Schclarek (2015) shows that lending by publicly and privately owned banks was reduced during the crisis.

[5]Empirical studies by Fazzari et al. (1988) and Whited (1992), for example, point to the conclusion that some firms have difficulties financing investment externally in normal times.

[6]See e.g. Chava & Purnanandam (2011) for empirical evidence for the U.S.. Their results imply that bank-dependent firms reduced capital expenditures to a larger extent than firms that had access to the public debt market.

et al. (2010) show that investments decline due to the crisis. They find in particular that firms are hit hardest if they have either low cash reserves, are financially constrained, or have their main field of operation in industries which rely heavily on external financing. Almeida et al. (2012) and Vermoesen et al. (2013) measure financing constraints by using firms' long-term debt maturing in the short run. Their findings evince that firms which had to refinance a large proportion of their long-term debt show a stronger reduction in investment. Cingano et al. (2016) investigate the investment pattern for a sample of Italian firms in the financial crisis. They show that banks that engaged highly in interbank market funding reduced their firm-lending to a higher extent and firms reduced their investments in result.

Obtaining external financing might be even more difficult if the firm is engaged in innovation. Innovative firms may face higher business risks in general (Hall 2002). Besides lower marginal costs, investment into a new technology will imply technological risks, high fixed costs and uncertainty concerning market success. Uncertainty about returns and their variance makes the evaluation of the innovator's activity difficult for lenders (Magri 2009). In addition, successful innovators are interested in keeping their ideas secret, such that potential lenders will receive a lower quality signal (e.g. Bhattacharya & Ritter 1983).[7] Empirical studies underline this theoretical finding that innovative firms have problems accessing external financing like bank loans (e.g. Freel 2007; Mina et al. 2013; Schneider & Veugelers 2010). Nevertheless, Ayyagari et al. (2011) show a positive relation between the use of external financing for investment activity and the degree of firm innovation. Moreover, innovative firms face adverse selection and moral hazard problems which limit their ability to substitute the financing source (e.g. Holmstrom & Tirole 1997). Consequently, frictions on the financial markets likely affect innovative firms more than their non-innovative counterparts.

Empirically, it is shown that financing problems in the financial crisis are indeed particularly prevalent for innovative firms (Lee et al. 2015; North et al. 2013). Lee et al. (2015) analyze a sample of more than 10000 UK SME employers from government surveys in 2007/8, 2010 and 2012, and investigate applications for external finance. Although both innovators and non-innovators have difficulties in accessing external finance, the innovators experience more frequent problems to receive a credit at all. North et al. (2013) consider a sample of UK technology firms and show that the innovators experience less favorable access to external finance in the crisis.

Consequently, if we consider investment as an internally and externally financed activity, we would expect it to decrease if availability of external financing is constrained. Our main interest is the difference in the degree of financial constraints between innovative and non-innovative firms in the financial crisis. Thus, combining both theoretical and empirical

[7] In contrast to this finding, works like Hottenrott et al. (2016) and Hochberg et al. (2018) show that patents could also serve as a quality signal.

findings to compare investment behavior of innovative and non-innovative firms in the financial crisis, we can formulate the following hypotheses:

H1: Among firms using external finance, innovative firms reduce capital investments by a larger amount than non-innovative firms.

H2: Among innovative firms, those using external finance reduce their investments in capital goods more than those that are not using external finance.

2.3 Data and methodology

2.3.1 Data and variables

This study uses the IAB Establishment Panel[8], waves 2004-2012 (covering the years 2004 to 2011).[9] Data access was provided via subsequently remote data access. The IAB panel has been collecting yearly observations from West German establishments since 1993 and East German ones since 1996.[10] The main emphasis of the panel is on labor demand and firm-specific determinants of employment. However, in addition to these topics other interesting information on innovation and investment is also collected. On an irregular basis special questions are added to the survey. These sometimes focus, for example, on the financial crisis and its effects on firms.

Our panel consists of 616 firms from the manufacturing sector. Each firm is sampled at least twice in the years 2004 to 2011, such that each firm is observed at least once before 2008 and once after 2008. Moreover, we restrict our sample to observations which are either independent companies or independent organizations without other business locations. Additionally, we include observations of head offices of an enterprise. Thus, we are able to observe each business unit and neglect effects, for example, from branches which might not make autonomous decisions on investments. As we will consider selectivity in the next stage of the analysis, we have to restrict the sample further. For details see Section 2.3.3.

Innovativeness is defined as the introduction of a product new to the market (not just new to the firm).[11] Introduction of a product which is new to the market (and not just for

[8] See e.g. Ellguth et al. (2014) for a description of the IAB establishment panel and the survey methodology.

[9] Questions necessary to our empirical investigation are mostly asked for the previous year, e.g. the investment value of 2009 is surveyed in the wave 2010.

[10] The sample of each survey wave comprises about 16,000 firms per year. Sampled firms stem from an establishment file from the Federal Employment Agency and have to employ at least on employee covered by social security (Ellguth et al. 2014). According to Ellguth et al. (2014) an optimum stratification mechanism is applied to draw the specific enterprises by using the following stratification variables: size classes, 19 sectors and federal states. Due to this mechanism, sampling probability increases with establishment size. About 23% of the establishments sampled for the 2012 survey stem from the manufacturing industry (i.e. NACE Rev 2.0 codes 10 to 33) (Ellguth et al. 2014). Firms are sampled repeatedly if they responded once.

[11] For a similar procedure see Freel (2007), Mina et al. (2013) and Lee et al. (2015).

the firm) is usually a risky undertaking[12], and therefore this variable is well suited to our research question of risk and availability of external finance.[13] For identification we use the following question from the survey waves 2007 and 2008: "Have you started to offer a completely new product or service within the last two years for which a new market had to be created?" with the possible answers: "Yes" and "No". From this question we are able to construct a variable 'Inno' which takes unit value if the firm introduced at least one product innovation in the years 2005 to 2007 and zero if not. We use this question from 2007 and 2008 because the covered years 2005 to 2007 were the last ones before the crisis broke out. Assuming that these firms are innovators is in line with the findings in Peters (2009). She shows a persistency of innovation, in such a way that past innovators are more likely to be innovators in the future.

We identify firms using external means to finance their capital investments in the pre-crisis sample period by a question from the survey waves 2005 and 2008. Firms were asked[14] how they financed their investments in the previous year and could choose from the following responses: current receipts like cash flow; other internal resources like venture capital or capital increase; private loans; or subsidies.[15] Firms using private loans are likely to have internal constraints and we expect them to be forced to use the more costly external finance.[16] We generate a dummy variable 'ExtFin' which takes unit value if the firm uses private loans to finance their capital investments and zero if not. Furthermore, we are able to build combinations from the Inno and ExtFin variables, which are given in Table 2.1.

[12]The technological uncertainty depends on the characteristics (e.g. novelty) of the project (e.g. Shenhar & Dvir 1996).

[13]Czarnitzki & Hottenrott (2011a) show that financing constraints are more binding for innovators introducing a novelty to the market (cutting-edge R&D performers) by comparing them with firms that either imitate or improve products (routine R&D performers). Moreover, it is shown that a relation between financing risk and technology uncertainty exists which is particularly important for startups (e.g. Nanda & Rhodes-Kropf 2013; Nanda & Rhodes-Kropf 2016).

[14]The question reads as follows: "Which of the following sources of finance were used for the total investment in 2007 reported in question 19? Please indicate how this amount is distributed across the different sources.". The answer opportunities are "Current receipts (cash flow)"; "Other internal resources (capital increase due to corporate merger, shareholders, venture capital companies, stock issues)"; "Private credit (from banks, credit unions, saving banks, enterprises)"; or "Subsidies (investment subsidies, investment grants, public bank credits)".

[15]Detailed summary statistics for these financing sources are shown in Appendix 2.6.1, Tables 2.8 and 2.9. These indicate that the most of the external funding comes from private credit.

[16]The marginal costs of capital for external means are higher than for internal means (David et al. 2000; Hall 2002; Hottenrott & Peters 2012).

Table 2.1: Combinations of innovator status and use of external finance

External finance usage (ExtFin)	Innovator status (Inno)	
	Non-innovator (N=2275)	Innovator (N=1561)
No external finance (N=2026)	$Inno_0ExtFin_0$ (N=1233)	$Inno_1ExtFin_0$ (N=793)
External finance (N=1810)	$Inno_0ExtFin_1$ (N=1042)	$Inno_1ExtFin_1$ (N=768)

Note: Frequencies are shown in parentheses.

We add several control variables commonly used in the literature. First, we use firms' sales growth 'Salesgrowth' lagged by one year as a proxy for Tobin's Q. We do not have explicit information on the financials of the sampled firms. Therefore, we follow Behr et al. (2013), who use lagged sales growth as a proxy for growth and investment opportunities. Furthermore, we include the lagged logarithm of employees 'ln(Size)', to control for size-specific investment effects. To control for internal resources, we include a dummy variable lagged by one year 'Profit' which accounts for the previous year's profit situation. The profit situation is evaluated yearly on a 5-point scale ranging from very good to unsatisfactory. The dummy takes unit value if the firm reports at least a good situation and zero if the situation was reported as satisfactory or worse. We employ a dummy variable 'Export' which takes unit value if the firm has realized sales in foreign countries in the previous year and zero if not. We deal with the issue that the firms could have carried out a service innovation instead of a product innovation by only using observations from the manufacturing sector.

Our dependent variable comprises capital investments. First, inspections of the variable revealed that about 17% of the firms in our sample reported zero investments. According to Jensen & Rässler (2006), reported zero values are likewise rooted in a lack of knowledge on investment size or unwillingness to report a value. Thus, we discard these observations from our analysis.[17] Finally, we apply a logarithmic transformation to the capital investments variable.

Descriptive statistics for our sample of 3836 firm-year observations are presented in Table 2.2. As given, roughly 41 percent of the firms are innovative and about 47 percent use external means to finance their investments. The relating group compositions show that about 32 percent of the firms are neither innovators nor using external financing sources. The mean of investment is 2.246 million and differs for each of the subgroups. The group of innovators not using external finance shows the highest values of growth in

[17]Dropping the zero values might lead to selectivity problems as we find in line with Jensen & Rässler (2006) that for example smaller entities are more likely to report zero investments. However, we show in the limitations and robustness tests Section 2.4.5 that our results are unaffected by handling the zero values in different ways.

sales (0.071), size (373.391) and profits (0.518) compared to all other groups. The values of investment, size and export in the innovator groups are higher than their non-innovative counterparts with equal use of external means.

Table 2.2: Descriptive statistics

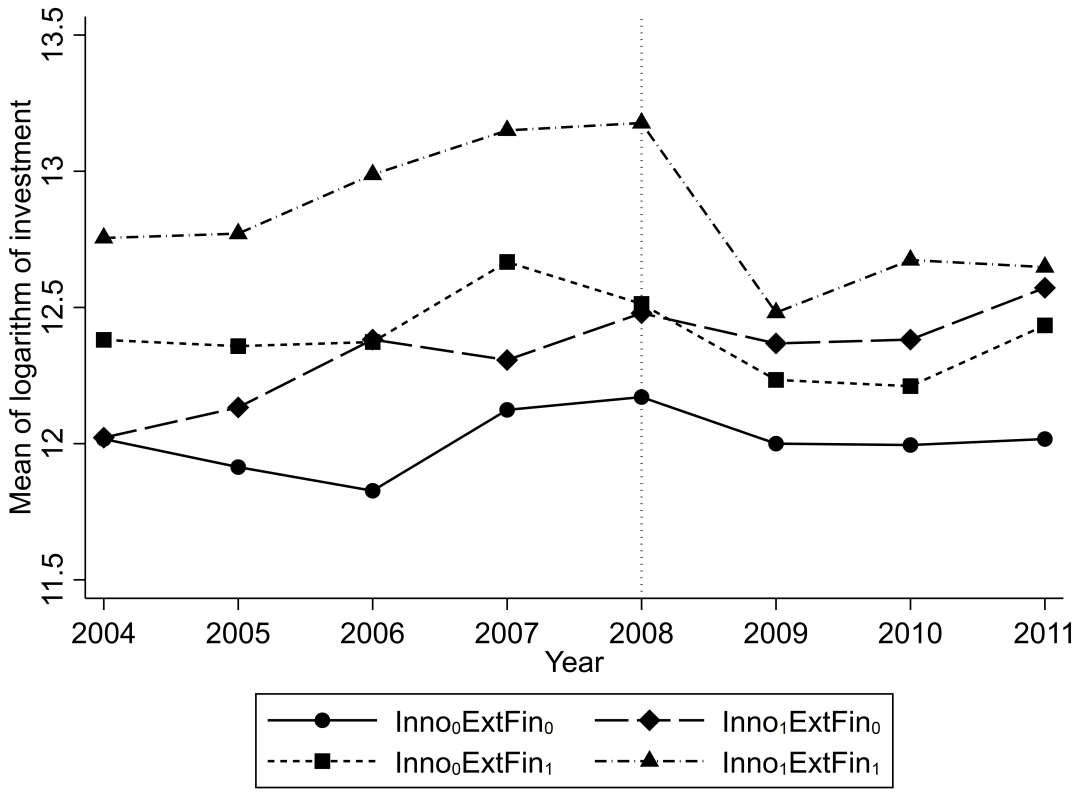
Sample	Variable	Mean	SD	Min	Max	Mean difference (p-value)
Full sample;	Inno	0.407	0.491	0	1	
N=3836	Extfin	0.472	0.499	0	1	
	$Inno_0ExtFin_0$	0.321	0.467	0	1	
	$Inno_1ExtFin_0$	0.207	0.405	0	1	
	$Inno_0ExtFin_1$	0.272	0.445	0	1	
	$Inno_1ExtFin_1$	0.200	0.400	0	1	
	Investment (Mio.)	2.246	15.200	0.0002	438	
	Investment/Sales	0.057	0.086	0.00003	1.471	
	Salesgrowth	0.067	0.280	−0.936	7.200	
	Size	242.825	1600.342	2	49221	
	Export	0.665	0.472	0	1	
	Profit	0.472	0.499	0	1	
Subsample;	Investment (Mio.)	2.952	18.300	0.000	417	0.048
$Inno_0ExtFin_0$	Investment/Sales	0.045	0.071	0.000	1	0.000
N=1233	Salesgrowth	0.066	0.272	−0.877	3.839	0.941
	Size	276.009	1419.923	2	20015	0.377
	Export	0.612	0.487	0	1	0.000
	Profit	0.459	0.499	0	1	0.255
Subsample;	Investment (Mio.)	3.085	23.800	0.001	438	0.082
$Inno_1ExtFin_0$	Investment/Sales	0.055	0.094	0.000	1.471	0.546
N=793	Salesgrowth	0.071	0.361	−0.682	7.200	0.681
	Size	373.391	3011.727	2	49221	0.010
	Export	0.736	0.441	0	1	0.000
	Profit	0.518	0.500	0	1	0.004
Subsample;	Investment (Mio.)	1.256	4.186	0.001	87	0.014
$Inno_0ExtFin_1$	Investment/Sales	0.067	0.096	0.000	1.238	0.000
N=1042	Salesgrowth	0.069	0.264	−0.936	2.846	0.804
	Size	135.738	231.813	2	1752	0.011
	Export	0.597	0.491	0	1	0.000
	Profit	0.460	0.499	0	1	0.337
Subsample;	Investment (Mio.)	1.590	3.556	0.000	40.800	0.182
$Inno_1ExtFin_1$	Investment/Sales	0.064	0.084	0.000	1.023	0.011
N=768	Salesgrowth	0.061	0.207	−0.574	1.162	0.545
	Size	200.026	301.774	2	1950	0.407
	Export	0.767	0.423	0	1	0.000
	Profit	0.464	0.499	0	1	0.584

Note: The column showing the mean difference displays the p-value for the test on mean difference between the group indicated in the row and all other groups.

Figure 2.1 shows investment patterns for each of the above described sub-groups. Among the external financing usage groups, the innovative firms show a higher initial level of investments in the period 2004 to 2008. However, the graphical inspection reveals that the innovator groups show a stronger decline in investments compared to the non-innovator

groups after 2008. The decrease is strongest for the group of innovators using external financing.

Figure 2.1: Logarithm of investment per group over time



Note: The vertical dotted line indicates the beginning of the crisis period.

2.3.2 Empirical methodology

To test for our hypotheses, we combine the specific realizations with respect to innovation and financing. This leads to a multiple treatment constellation. We employ the difference-in-differences estimation method. Using this estimation strategy has two advantages: On the one hand, we are able to control for common effects like macroeconomic conditions and, on the other hand, the approach takes into account unobserved individual, time-invariant effects. In particular, we use the following fixed-effects regression to account for further firm-specific time invariant effects[18]:

$$y_{it} = \beta_1 + \tau_1 \text{Inno}_1\text{ExtFin}_0 \times \text{Crisis} + \tau_2 \text{Inno}_0\text{ExtFin}_1 \times \text{Crisis} \tag{2.1}$$
$$+ \ \tau_3 \text{Inno}_1\text{ExtFin}_1 \times \text{Crisis} + \sum_k \beta_k X_{k,t-1} + \sum_{t=2005}^{2011} \text{year}_t + \alpha_i + \varepsilon_{it}$$

[18]We are aware that the strict exogeneity assumption of the fixed-effects estimator is possibly violated. OLS estimates, reported in the limitations and robustness tests Section 2.4.5 indicate that our results also hold in the simple, linear context.

Our primary dependent variable y_{it} is the logarithm of investments in capital goods ln(Invest). The dummy variables $\text{Inno}_1\text{ExtFin}_0$, $\text{Inno}_0\text{ExtFin}_1$ and $\text{Inno}_1\text{ExtFin}_1$ are implemented as described above. They are interacted with the Crisis variable. Thus, the value zero is assigned if one of the periods before the emergence of the crisis is considered (2004 – 2007). $X_{k,t-1}$ includes the lagged, time-varying variables 'Salesgrowth', 'ln(Size)', 'Export' and 'Profit' as described above. In addition, we include year fixed effects denoted as $year_t$ and firm fixed effects α_i.

Non-innovative firms and firms not using external financing sources are assumed to be unaffected. Therefore, we use firms which exhibit both characteristics ($\text{Inno}_0\text{ExtFin}_0$) as the control group. The implemented group dummies measure the separate treatment effect for each group compared to the control group of non-innovators, forgoing external means. Moreover, it is possible to test whether the treatment groups are differently affected by the crisis. This is done by comparing the coefficients of innovators using external and non-external means as well as the coefficients of innovators and non-innovators in the group of firms using external finance.[19]

The first hypothesis states that innovators among the firms using external sources are affected to a larger extent than non-innovators. To prove this, we have to observe the following results: In the group of firms using external financing, both innovative and non-innovative firms are more affected than non-innovative firms ($\tau_2 > \tau_3$). Our second hypotheses will be confirmed if, among the innovators, those firms that used private loans were more affected by the crisis. This in turn requires that, among innovators, firms using external financial means are affected to a larger extent ($\tau_1 > \tau_3$).

2.3.3 Dealing with selectivity

Being an innovative or a non-innovative firm is hardly the outcome of a random process. Both types of firms might well be fundamentally different and these differences might in turn affect behavior during the financial crisis. To overcome the possible differences between both groups, we rely on coarsened exact matching (CEM) to balance our sample (Blackwell et al. 2009; Iacus et al. 2012).[20] Among other advantages, according to Iacus et al. (2011) and Blackwell et al. (2009), this method leads to lower model dependence and average treatment-effect estimation error.

We match innovative and non-innovative firms according to their joint distribution on variables as of 2006 that are common in the literature to determine the innovator status. Thus, firms are grouped in 2006 according to their situation before the financial crisis took effect. We utilize dummy variables reflecting exporting behavior, liability status of

[19]Using this approach, we avoid splitting the sample and applying a separate difference-in-differences regression for each sample. Moreover, we are able to compare the coefficients across groups.

[20]Recent examples using coarsened exact matching are Azoulay et al. (2010), Ching (2016) as well as Singh & Agrawal (2011).

the firm, location in eastern Germany and profit situation. As we are aware that investments are size-dependent, we include a variable for firm size, measured as the number of employees. In addition, we use a dummy indicating whether machinery is in good condition as a proxy for productivity. Furthermore, we include a dummy variable controlling whether the firm was founded before or after 1990. According to Hall et al. (2012), investments in ICT are an input contributing to innovation. Thus, we add a dummy if the firm undertakes this kind of investment.

Aforementioned variables are used to match the groups according to the joint distribution of the covariates. First, we eliminate observations with missing values before binning the variables to create intervals for the matching of the treated and control group. For the continuous size variable, we rely on the program's default binning algorithm (Sturge's rule) to coarsen the variable. Using the CEM approach, we first eliminate firms from our sample that are not comparable to the innovator group at all. This is necessary since CEM does not rely on common support assumptions such as propensity score matching (Blackwell et al. 2009). Next, exact matching is applied to match the group of firms according to the created intervals of each variable.

We are able to assess the quality of our approach by comparing the imbalance between both groups by the measure $0 \leq \mathcal{L} \leq 1$ before and after the matching procedure.[21] The results show that we reduce the imbalance from $\mathcal{L}_1 = 0.257$ to $\mathcal{L}_2 = 0.026$. In order to control for the potential difference between both groups we run all estimations using the weights generated from the CEM procedure.

2.4 Results

2.4.1 Basic estimation results

Regression results for Equation (2.1) are given in Table 2.3, Columns (1) to (4). First, we observe that each interaction variable comprising the use of external financing is negative and significant at least at the ten percent level.[22] Therefore, each of these constructed groups is likewise more affected by the crisis in terms of investment behavior than the group of non-innovators not using private loans.

We first test for the influence of external finance on innovators and non-innovators. We observe that both interactions are negative and highly significant. The relation $\tau_2 > \tau_3$ finds support by the significant differences between the two coefficients according to the

[21] Perfect balance is indicated by $\mathcal{L} = 0$.

[22] For interpretation purposes, we follow Giles (1982), Halvorsen & Palmquist (1980) as well as van Garderen & Shah (2002) when interpreting the coefficient of a dummy variable in a semilogarithmic estimation. For an estimated coefficient β, the corresponding percentage change is calculated as $100(exp(\beta) - 1)$.

results presented in Columns (1), (2) and (4). Based on the specification shown in Column (3) no significant difference is estimated.

Next, we analyze the coefficients for τ_1 and τ_3 to evaluate whether innovators using external financing are more affected by the shortage on capital markets. The coefficient τ_1 is not significant at conventional levels in Columns (1) to (4). In addition, in all four Columns τ_3 is negative and significant at the 1 percent level. The estimated coefficient in Column (4) implies that innovators using private loans reduce investments during the crisis by about 38 percent compared to non-innovators not using private loans. Moreover, the p-value at the bottom of the table shows that $\tau_1 > \tau_3$ holds in each model. In conclusion, among innovators, firms using external finance are more strongly affected than firms which forgo external means.

Table 2.3: Results for the multiple-treatment group comparison

	(1)	(2)	(3)	(4)
	Non-CEM-weighted		CEM-weighted	
Dependent variable	ln(Invest)	ln(Invest)	ln(Invest)	ln(Invest)
$\text{Inno}_1\text{ExtFin}_0 \times \text{Crisis}$ (τ_1)	−0.018	−0.003	−0.049	−0.036
	(0.109)	(0.107)	(0.115)	(0.113)
$\text{Inno}_0\text{ExtFin}_1 \times \text{Crisis}$ (τ_2)	−0.260**	−0.244**	−0.303**	−0.278*
	(0.111)	(0.108)	(0.148)	(0.143)
$\text{Inno}_1\text{ExtFin}_1 \times \text{Crisis}$ (τ_3)	−0.440***	−0.437***	−0.475***	−0.474***
	(0.110)	(0.108)	(0.116)	(0.114)
Salesgrowth		0.194*		0.175
		(0.118)		(0.121)
ln(Size)		0.336**		0.398**
		(0.149)		(0.173)
Export		0.039		0.063
		(0.102)		(0.115)
Profit		0.220***		0.202***
		(0.048)		(0.053)
Constant	12.563***	10.987***	12.784***	10.859***
	(0.077)	(0.645)	(0.087)	(0.790)
Tests				
$\tau_1 > \tau_2$ p-value	0.025	0.023	0.049	0.052
$\tau_1 > \tau_3$ p-value	0.000	0.000	0.000	0.000
$\tau_2 > \tau_3$ p-value	0.075	0.056	0.132	0.094
Year fixed effects	Yes	Yes	Yes	Yes
R-squared	0.825	0.828	0.833	0.835
Observations	3836	3836	3836	3836

Notes: Cluster-robust standard errors in parentheses. Clustered at the firm level. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level. P-values at the bottom of the table indicate whether to reject H_0 of the following one-sided test: $H_0 : \tau_i \leq \tau_j$ against $H_1 : \tau_i > \tau_j$.

2.4.2 Test for common trend assumption

In this section, we test for the common trend assumption, which is crucial for the validity of the difference-in-differences interpretation. The assumption implies that in absence of the treatment, the treatment and control group(s) would follow the same common trend. Besides graphical inspections, which are likewise not exact and are open to speculation, a regression approach allows for testing the assumption. According to Mora & Reggio (2015)[23] a regression of the following form is a suitable test for the assumption:

$$\begin{aligned} y_{it} = \beta_1 &+ \tau_1 \text{ Inno}_1\text{ExtFin}_0 + \tau_2 \text{ Inno}_0\text{ExtFin}_1 + \tau_3 \text{ Inno}_1\text{ExtFin}_1 \\ &+ \sum_{t=2005}^{2011} \tau_{1,t} \text{ Inno}_1\text{ExtFin}_0 \times \text{year}_t + \sum_{t=2005}^{2011} \tau_{2,t} \text{ Inno}_0\text{ExtFin}_1 \times \text{year}_t \\ &+ \sum_{t=2005}^{2011} \tau_{3,t} \text{ Inno}_1\text{ExtFin}_1 + \sum_k \beta_k X_{k,t-1} + \sum_{t=2005}^{2011} \text{year}_t + \alpha_i + \varepsilon_{it} \end{aligned} \tag{2.2}$$

For the common trend assumption to hold, the coefficients $\tau_{1,t}$, $\tau_{2,t}$ and $\tau_{3,t}$ for the pre-crisis period up to 2008 have to be jointly insignificant. The result of the respective F-test is given in Table 2.4. As is shown, the required insignificance of the pre-crisis year-type interaction is observed.[24] Consequently, the common trend assumption holds and the groups would follow the same trend if the crisis had not happened.

Table 2.4: Test for the common trend assumption

	(1) Non-CEM-weighted	(2) CEM-weighted
Dependent variable	ln(Invest)	ln(Invest)
$H_0 : \tau_{1,t} = 0 \ \ \forall \ \ t < 2008$ p-value	0.174	0.197
$H_0 : \tau_{2,t} = 0 \ \ \forall \ \ t < 2008$ p-value	0.449	0.493
$H_0 : \tau_{3,t} = 0 \ \ \forall \ \ t < 2008$ p-value	0.534	0.721
Year fixed effects	Yes	Yes
Firm controls	Yes	Yes
R-squared	0.830	0.837
Observations	3836	3836

Notes: P-values indicate the result of a test on the joint significance of the pre-crisis interaction coefficients. The null Hypothesis is that the coefficients jointly exert no effect.

In addition, we can also test for heterogeneity of treatment effects over the time periods. We re-estimate Equation (2.1) and replace the treatment times crisis variables with interaction terms of the treatment variable with each post-treatment year dummy. Put more simply, we can check whether the treatment effect was e.g. particularly strong in 2009, but eventually attenuated in 2011. Thus, the coefficients for the post-crisis interac-

[23] See Hangoma et al. (2018) and Yamamura (2016) for recent applications.

[24] See Table 2.10 in Appendix 2.6.2 for the detailed regression output. All pre-crisis coefficients are also individually insignificant.

tion from 2008 to 2011 show how the effect evolves over time. As given in Table 2.5, for the group of firms using external finance, which are not innovative, the coefficient of the year-type interaction is significantly different from zero at the 10 percent level from 2010 to 2011 (Column (1)). Nevertheless, the coefficients are not significantly different from each other and, therefore, we do not find evidence that the treatment effects change over time; in particular, they do not become smaller. For the group of innovators and firms using external finance, the picture changes. The coefficients of year-type interaction effects from 2009 to 2011 are significant at least the 5 percent level. However, the coefficients are statistically not different from each other.

Table 2.5: Test for the heterogeneity of the treatment effect

	(1) Non-CEM-weighted	(2) CEM-weighted
Dependent variable	ln(Invest)	ln(Invest)
$\text{Inno}_1\text{ExtFin}_0 \times 2008$	−0.049	−0.118
	(0.130)	(0.138)
$\text{Inno}_1\text{ExtFin}_0 \times 2009$	−0.057	−0.135
	(0.164)	(0.178)
$\text{Inno}_1\text{ExtFin}_0 \times 2010$	0.090	0.057
	(0.167)	(0.174)
$\text{Inno}_1\text{ExtFin}_0 \times 2011$	−0.028	0.042
	(0.162)	(0.171)
$\text{Inno}_0\text{ExtFin}_1 \times 2008$	−0.151	−0.185
	(0.137)	(0.172)
$\text{Inno}_0\text{ExtFin}_1 \times 2009$	−0.224	−0.297
	(0.157)	(0.215)
$\text{Inno}_0\text{ExtFin}_1 \times 2010$	−0.302*	−0.313
	(0.170)	(0.196)
$\text{Inno}_0\text{ExtFin}_1 \times 2011$	−0.363**	−0.361*
	(0.155)	(0.195)
$\text{Inno}_1\text{ExtFin}_1 \times 2008$	−0.151	−0.222
	(0.147)	(0.154)
$\text{Inno}_1\text{ExtFin}_1 \times 2009$	−0.586***	−0.664***
	(0.163)	(0.178)
$\text{Inno}_1\text{ExtFin}_1 \times 2010$	−0.547***	−0.583***
	(0.188)	(0.195)
$\text{Inno}_1\text{ExtFin}_1 \times 2011$	−0.624***	−0.553**
	(0.211)	(0.218)
Constant	11.129***	10.949***
	(0.659)	(0.808)
Year fixed effects	Yes	Yes
Firm controls	Yes	Yes
R-squared	0.829	0.836
Observations	3836	3836

Notes: Cluster-robust standard errors in parentheses. Clustered at the firm level. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

2.4.3 Controlling for demand expectations

The literature (e.g. Aghion et al. 2010) points out that short-run investment in principle should be pro-cyclical and long-run investment counter-cyclical, as both kinds of expense are alternative uses of financial resources. The basic idea is that scarce financial resources are employed for current production (and the extension of production capacities) if demand is high (boom phase). Moreover, scarce resources are expected to be predominantly invested in long-run growth opportunities like R&D if demand is stagnating or shrinks (recession phase)[25].[26]

The financial crisis not only hit banks, it undoubtedly exerted negative effects on aggregate demand. Uncertainty during the crisis on future economic prospects led consumers to exercise restraint and to postpone intended purchases of consumer goods (Kahle & Stulz 2013). If investment is cut, this could be caused by firms' pessimistic expectations of future demand, by insufficient supply of external financing, or both. Following this argumentation, negative demand expectations would reduce capital expenditures due to lacking growth opportunities (Kahle & Stulz 2013). Our strategy to identify the demand expectations is to pose a question that asks for an evaluation of the development of business volume in the current year compared to the previous year. We generate a dummy variable Sales_Exp which takes unit value if the firm expects business volume to remain constant or increase. The value zero is assigned if the firm expects a fall in demand.[27] We use this variable with a one year lag as an additional control variable in Equation (2.1) to proxy expected demand growth. Results for the test are shown in Table 2.6. Although the number of observations decreased, compared to Table 2.3 the coefficients of the interactions of interest do not change much. The added variable concerning sales expectations turns out to be significant at least at the ten percent level.

[25] cf. e.g. Barlevy (2007)

[26] See Knudsen & Lien (2014) for a detailed discussion concerning the effect of demand and financing constraints on capital investments and R&D in an economic downturn. Capital investments react negatively to demand reductions (Knudsen & Lien 2014). For R&D, the strength of the demand reduction is important to determine its effect. Moderate reductions in demand might foster R&D as the reduction in internal means is not too large (Knudsen & Lien 2014). Strong reductions in demand in contrast lead to shrinking R&D expenditures. This might be rooted in decreased internal means and lower investment incentives (Knudsen & Lien 2014; Schmookler 1966). Financing constraints however dominate both effects and lead to a reduction in R&D expenditures (Knudsen & Lien 2014).

[27] We assign missing values if the firm has no expectation about future demand.

Table 2.6: Controlling for demand expectations

	(1) Non-CEM-weighted	(2) CEM-weighted
Dependent variable	ln(Invest)	ln(Invest)
$\text{Inno}_1\text{ExtFin}_0 \times \text{Crisis}$ (τ_1)	0.071	0.060
	(0.109)	(0.112)
$\text{Inno}_0\text{ExtFin}_1 \times \text{Crisis}$ (τ_2)	−0.213**	−0.209
	(0.108)	(0.140)
$\text{Inno}_1\text{ExtFin}_1 \times \text{Crisis}$ (τ_3)	−0.422***	−0.436***
	(0.107)	(0.110)
Sales_Exp	0.148***	0.111*
	(0.057)	(0.064)
Constant	10.477***	10.447***
	(0.641)	(0.785)
Tests		
$\tau_1 > \tau_2$ p-value	0.011	0.037
$\tau_1 > \tau_3$ p-value	0.000	0.000
$\tau_2 > \tau_3$ p-value	0.044	0.064
Year fixed effects	Yes	Yes
R-squared	0.831	0.837
Observations	3646	3646

Notes: Cluster-robust standard errors in parentheses. Clustered at the firm level. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level. P-values at the bottom of the table indicate whether to reject H_0 of the following one-sided test: $H_0 : \tau_i \leq \tau_j$ against $H_1 : \tau_i > \tau_j$.

2.4.4 Testing for other financing channels

An alternative to external financing by debt is external financing by equity. Equity financing is not as frequently used in Germany as in the US, for example, but about 24% of our sample use equity to finance investment[28]. Hence, equity is not negligible. As argued above, if external finance is not available, firms might use additional equity as an alternative if this option is available to them. For a sample of Italian firms, Magri (2009) show that issuing new equity is an option, and according to Carpenter & Petersen (2002), small innovative firms in particular are able to relax their financing constraints with new equity. In a similar vein, Aghion et al. (2004) show that R&D-intensive firms in principle prefer debt, but the likelihood of using equity issuance as an alternative increases with the innovativeness of firms. Brown et al. (2009) point out that, aside of cash flow, external

[28]The information on equity includes venture capital for newly founded firms. Venture capital may remove the sensitivity of investment on cash-flow and financial constraints (Bertoni et al. 2010). Engel & Keilbach (2007) show the importance of venture capital for employment growth and Bertoni & Tykvov (2015) explore the differences between governmental and independent venture capital investors concerning invention and innovation. Nevertheless, the sample of firms using venture capital is very small in Germany (see e.g. Engel & Keilbach 2007; Gottschalk & Licht 2013).

equity is an important source for young firms to finance R&D. Shifts in the supply of internal and external equity relaxed financial constraints for young firms in the U.S. during the 1990s. However, during the financial crisis and in times of general high uncertainty the equity providers might also be reluctant to supply additional capital.

We cannot use equity as a simple control variable in our fixed effects estimation, as it does not vary over time. Alternatively, we repeat our empirical analysis and add equity financing. Accordingly, we include the availability of equity to finance investment (before the crisis evolved) in our specification. Our new variable 'Equity' assumes the value zero if firms have not financed their investment through equity during the pre-crisis period. Equity takes unit value if the firm has obtained equity to finance investment. The results are presented in Table 2.7. Interestingly we do not find a significant effect of the crisis when only equity was used as additional financing source (τ_4 and τ_5). Moreover, for the group of non-innovators using debt financing, the coefficient (τ_2) turns out to be insignificant now. However, we find that innovators and non-innovators using equity and debt financing (τ_6 and τ_7) reduce their investment spending in the crisis compared to firms which are non-innovative and using neither source of additional financing. This indicates that these firms do not benefit from an additional financing source. This is probably because these firms are not able to substitute their financing source in the financial crisis but rely on external financing sources.

Table 2.7: Testing for equity financing

	(1) Non-CEM-weighted	(2) CEM-weighted
Dependent variable	ln(Invest)	ln(Invest)
$\text{Inno}_1\text{ExtFin}_0\text{Equity}_0 \times \text{Crisis}$ (τ_1)	−0.044	−0.036
	(0.121)	(0.125)
$\text{Inno}_0\text{ExtFin}_1\text{Equity}_0 \times \text{Crisis}$ (τ_2)	−0.167	−0.180
	(0.127)	(0.171)
$\text{Inno}_1\text{ExtFin}_1\text{Equity}_0 \times \text{Crisis}$ (τ_3)	−0.475***	−0.471***
	(0.121)	(0.126)
$\text{Inno}_0\text{ExtFin}_0\text{Equity}_1 \times \text{Crisis}$ (τ_4)	−0.151	0.007
	(0.165)	(0.189)
$\text{Inno}_1\text{ExtFin}_0\text{Equity}_1 \times \text{Crisis}$ (τ_5)	−0.022	−0.023
	(0.189)	(0.192)
$\text{Inno}_0\text{ExtFin}_1\text{Equity}_1 \times \text{Crisis}$ (τ_6)	−0.536***	−0.508**
	(0.160)	(0.212)
$\text{Inno}_1\text{ExtFin}_1\text{Equity}_1 \times \text{Crisis}$ (τ_7)	−0.471**	−0.476**
	(0.198)	(0.202)
Constant	10.990***	10.860***
	(0.655)	(0.798)
Tests		
$\tau_1 > \tau_2$ p-value	0.196	0.211
$\tau_1 > \tau_3$ p-value	0.001	0.001
$\tau_2 > \tau_3$ p-value	0.016	0.053
$\tau_5 = \tau_1$ p-value	0.913	0.948
$\tau_6 = \tau_2$ p-value	0.037	0.188
$\tau_7 = \tau_3$ p-value	0.986	0.980
Year fixed effects	Yes	Yes
Firm controls	Yes	Yes
R-squared	0.829	0.836
Observations	3836	3836

Notes: Cluster-robust standard errors in parentheses. Clustered at the firm level. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level. P-values at the bottom of the table indicate whether to reject H_0 of the following one-sided test: $H_0 : \tau_i \leq \tau_j$ against $H_1 : \tau_i > \tau_j$. The subsequent three p-values belong to the following two-sided test: $H_0 : \tau_i = \tau_j$ against $H_1 : \tau_i \neq \tau_j$.

2.4.5 Limitations and robustness tests

In this section we report the results of several additional robustness tests. The results of these tests are available in Appendix 2.6.3. First, we make changes to the regression technique and manipulate the outcome variable. We are aware that the strict exogeneity assumption necessary for the fixed-effects estimator might not hold. Thus, we re-estimate the specification (2.1) using an OLS model. The results are quite similar to our baseline results presented in Table 2.3. In addition, we use a fixed effects Poisson quasi-maximum

likelihood (QML) estimator.[29] Utilizing this estimator is advantageous because it can be applied to continuous variables (Silva & Tenreyro 2006; Wooldridge 1999a) and the calculated standard errors are robust to serial correlation (Wooldridge 1999a; Wooldridge 1999b).[30] The results of re-estimating Equation (2.1) are quite comparable to the baseline results in Table 2.3. The negative coefficient for innovators not using external financing is now significantly different from zero. The coefficient for non-innovators using external financing is no longer significantly different from zero. Next, we scale investments by sales. These variables express the importance of investment in relation to firm size. We estimate model (2.1) again using the fixed-effects technique and drop the sales growth variable. This might prevent biased coefficients from feedback effects from the dependent variables in earlier years to the present variables on the right-hand side (possible violation of the strict exogeneity assumption of the fixed-effects model). Nevertheless, the results are comparable to the results in the baseline specification.[31]

The next set of tests concentrates on the variable used for innovator status and the use of external financing. Our variable determining the innovator status of firms is based on realized innovations during the period 2005-2007. We use innovations before 2008 in order to apply a measure which is not affected by the crisis, but the three years might be too short a period to identify all firms working on innovation projects. Obviously, the distinction between innovators and non-innovators is crucial. Therefore, as an alternative we first defined innovators as those firms which have introduced at least one product new to the market over the whole sample period (2004 to 2011). Second, in order to apply a very different indicator of innovativeness, we defined firms as innovative if they belong to an industry which has an above median share of innovative firms based on our initial measure of innovation using introduction of new products[32]. Our results have been robust to these two changes in the innovation measure.[33]

Moreover, our measure of usage of external financing is just a dummy variable and not e.g. the percentage value of investment financed by external sources. Our zero-one distinction is used to classify the firms into groups and allow for difference-in-differences estimations. Descriptive statistics show that if firms use external financing at all, then this kind of financing represents a significant share of investment expenditures. To test for the sensitivity of our results to the use of zero percent versus any percentage as the distinction rule for identification of investment financing by external sources, we applied a further test and re-adjusted the cut-off value indicating whether firms belong to the group

[29] Although this approach is based on the fixed-effects Poisson model of Hausman et al. (1984), we use the approach proposed by Wooldridge (1999a). See e.g. Allison & Waterman (2002) for a discussion of the model proposed in Hausman et al. (1984). For other applications see e.g. Azoulay et al. (2010), Hussinger & Pellens (2019) as well as Mezzanotti & Simcoe (2019).

[30] This mitigates the problem of serial correlation highlighted by Bertrand et al. (2004).

[31] See Appendix 2.6.3, Table 2.11 for the results of these tests.

[32] Unfortunately, our measure of innovativeness is a zero-one variable, which does not allow for quantifying relative innovativeness with respect to the median innovation output in an industry.

[33] Results for these tests are shown in Appendix 2.6.3, Table 2.12, Columns (1) to (4).

of external financing users. Accordingly, firms that financed 25 percent or more of their investment by external means such as bank debt are considered to be external financing users. Firms using less than 25 percent are assumed to be non-external financing users. Our results are robust to this kind of change.[34]

Last, we are aware that we do not have access to firm balance sheet data and we must work with the information disclosed to the IAB. Thus, we are not able to assess whether investments have been postponed or abandoned if the investment amount decreased. Furthermore, as described with respect to the investment variable in Section 2.3.1, we had to account for the zero values of the investment variable. Discarding these observations might create a substantial bias in our estimates if the observations are not missing at random. We cannot rule out that this is not the case in our analysis. Thus, we apply two additional robustness checks to cope for this issue. For this purpose, we kept the zero observations and re-weighted all observations using the same CEM procedure as described in Section 2.3.3 for the extended sample. Imbalance was reduced from $\mathcal{L}_1 = 0.412$ to $\mathcal{L}_2 = 0.034$. For the first test, we follow Horton & Kleinman (2007) by applying an ad-hoc procedure to take account of the zero values. We keep the observations with zero values within the sample and construct a dummy variable which indicates whether the observations belong to this group. Next, we interact this dummy variable with all other explanatory variables in our model and add these new variables to our specification. Results of this exercise reveal that the coefficients of interest remain fairly robust to this change. In order to apply the second test, we impute investment values for the zero investment observations by applying Predictive Mean Matching (PMM, Rubin 1976). This method appeals to create imputed values for each of the zero values which allows for the re-estimation of the models presented in Table 2.3. We applied two variants of this procedure. First, we imputed one investment value for each zero investment observation. Second, we created 50 data sets with potential values for the zero investment values by imputation and applied multiple imputation regression techniques. Both procedures lead to results which are fairly in line with the previously presented results.[35]

2.5 Conclusion

This study analyzes the hypothesis that innovative firms and firms using external financing reduce their investment expenditures during the financial crisis to a larger extent than other firms. We use a variant of difference-in-differences estimations to analyze the effects of the financial crisis on investment behavior and take account of the four groups of firms (combinations of innovative/non-innovative/external finance/no external finance) considered. Our emphasis is on the differentiation between innovating and non-innovating

[34] See Table 2.12, Columns (5) and (6) in Appendix 2.6.3 for the estimation results.
[35] Estimation outcomes are shown in Table 2.13, Appendix 2.6.3.

firms, as there are theoretical arguments as to why innovative firms are more severely hit by the financial crisis. Estimations show that the impact of the crisis on investment by innovative firms is much greater than on investment by other firms. For firms using external financing, innovators reduced their investments more compared to non-innovators. Among innovators, those who use external sources for investment financing reduce their investment more than those firms that use other sources of finance. Thus, the multi-group comparisons lead to the result that the impact of the financial crisis on innovative firms that use external financing is indeed the strongest. In contrast, we do not find an effect for firms using only equity as an external source. However, firms suffer from the financial crisis if they use a mixture of equity and other debt-oriented external financing sources.

Obviously, as discussed in Section 2.4.5, our empirical investigation has some limitations but nevertheless we are convinced that our study adds to the literature on the relationship between external finance and investment activity during the financial crisis (e.g. Almeida et al. 2012; Campello et al. 2010; Duchin et al. 2010; Vermoesen et al. 2013) in general. While much has been written on the problems of externally financing R&D (e.g. Aghion et al. 2012; Czarnitzki 2006; Czarnitzki & Hottenrott 2011a; Czarnitzki & Hottenrott 2011b), and financial constraints for investment have also been investigated (e.g. by Fazzari et al. 1988; Whited 1992), differences between innovators and non-innovators on activities other than innovation have been considered to a much lesser degree. Our results show that firms' risk characteristics determine their access to external finance in general and partly determine undertakings other than just R&D projects. As the more risky firms, innovators have fewer chances to externally finance their investment. Positive externalities provide the most common justification of public funding for R&D-active firms. Public funding may serve as a substitute for insufficient external financing. However, innovative firms suffer not only from difficulties in financing R&D but also experience problems with respect to other capital-intensive expenses like investment. This may also be a reason to subsidize innovative firms. The combination of R&D and investment in capital stock largely determines growth, and both aspects are related on the one hand in realization and on the other hand in financing (problems). Moreover, we add evidence to the literature that investigates the access of innovative firms to external finance during the recent financial crisis (e.g. Lee et al. 2015; North et al. 2013). Our finding of stronger reduction in investment by innovative firms compared to their non-innovative counterparts shows outcome-based evidence of the problems of innovative firms during the recent financial crisis.

Summarizing, innovative firms were hit more severely by the financial crisis, had more problems than others in accessing external finance and this had an impact on their expenditures for investment. Given the importance of investment for the implementation of the outcome of innovative projects and of innovation for the growth of economies one might wonder whether our results could lead to policy implications. A possible measure would be a countercyclical public funding of investment projects undertaken by innovative firms.

In particular, if an economy suffers a very severe recession, additional help for innovators might be justifiable in order to substitute for the reduction in private financing. However, for such a recommendation more research is needed.

Moreover, our work has several implications for firms in bank-based systems. As highlighted above, these firms are likewise not able to access other sources of financing to a satisfying extent. Thus, strengthening venture capital financing in Germany as an additional or alternative financing source is one implication of our findings. This would lead to an improved possibility to substitute financing. Moreover, our results show that banking regulations like the strengthening of bank capital buffers are needed to maintain loan funding in times of distress on financial markets. Additionally, specific regulations might be necessary to support the credit supply to firms which face problems in accessing external financing due strong asymmetric information problems (e.g. innovative firms with riskier business models) when financial markets are under stress.

Furthermore, our results offer scope for implications for firms. An extensive literature shows that there is an impact of taxation on innovative behavior (e.g. Hall & van Reenen 2000). Thus, specific taxation and accounting rules might be beneficial to support innovative firms in times when access to external financing is weak. Moreover, the results presented in this paper imply that there is room for some managerial actions. This coincides with the equity financing argument made above. Thus, it might be beneficial for firms to rely more on equity to finance investments. Moreover, direct actions taken to reduce investment activity in the financial crisis might be not beneficial for the actual growth path of the firm. Consequently, relying on a riskier business model makes it necessary for managers to have an emergency plan for financing at hand, for example, to bridge distorted capital access.

2.6 Appendix

2.6.1 Descriptive statistics

Table 2.8: Descriptive statistics for financing sources – Dummy variables

Sample	Variable	Mean	SD
Full sample; N=3836	Current receipts like cash flow	0.927	0.261
	Private loans	0.472	0.499
	Other internal resources like venture capital or capital increase	0.253	0.435
	Subsidies	0.338	0.473
Subsample; $Inno_0ExtFin_0$ N=1233	Current receipts like cash flow	0.966	0.181
	Private loans	0.000	0.000
	Other internal resources like venture capital or capital increase	0.239	0.427
	Subsidies	0.205	0.404
Subsample; $Inno_1ExtFin_0$ N=793	Current receipts like cash flow	0.984	0.127
	Private loans	0.000	0.000
	Other internal resources like venture capital or capital increase	0.192	0.394
	Subsidies	0.228	0.420
Subsample; $Inno_0ExtFin_1$ N=1042	Current receipts like cash flow	0.851	0.356
	Private loans	1.000	0.000
	Other internal resources like venture capital or capital increase	0.308	0.462
	Subsidies	0.459	0.499
Subsample; $Inno_1ExtFin_1$ N=768	Current receipts like cash flow	0.908	0.290
	Private loans	1.000	0.000
	Other internal resources like venture capital or capital increase	0.263	0.441
	Subsidies	0.501	0.500

Table 2.9: Descriptive statistics for financing sources – Continuous measures

Sample	Variable	Mean	SD	P10	P25	P50	P75	P90
Full sample;	Current receipts like cash flow	0.656	0.336	0.100	0.425	0.700	1.000	1.000
N=3836	Private loans	0.204	0.277	0.000	0.000	0.000	0.355	0.640
	Other internal resources like venture capital or capital increase	0.080	0.182	0.000	0.000	0.000	0.025	0.300
	Subsidies	0.061	0.124	0.000	0.000	0.000	0.075	0.200
Subsample;	Current receipts like cash flow	0.850	0.254	0.500	0.750	1.000	1.000	1.000
$\text{Inno}_0\text{ExtFin}_0$	Private loans	0.000	0.000	0.000	0.000	0.000	0.000	0.000
N=1233	Other internal resources like venture capital or capital increase	0.115	0.239	0.000	0.000	0.000	0.000	0.500
	Subsidies	0.035	0.100	0.000	0.000	0.000	0.000	0.125
Subsample;	Current receipts like cash flow	0.897	0.208	0.700	0.870	1.000	1.000	1.000
$\text{Inno}_1\text{ExtFin}_0$	Private loans	0.000	0.000	0.000	0.000	0.000	0.000	0.000
N=793	Other internal resources like venture capital or capital increase	0.065	0.180	0.000	0.000	0.000	0.000	0.250
	Subsidies	0.038	0.107	0.000	0.000	0.000	0.000	0.150
Subsample;	Current receipts like cash flow	0.400	0.266	0.000	0.150	0.465	0.625	0.750
$\text{Inno}_0\text{ExtFin}_1$	Private loans	0.452	0.257	0.150	0.250	0.400	0.610	0.850
N=1042	Other internal resources like venture capital or capital increase	0.057	0.109	0.000	0.000	0.000	0.100	0.225
	Subsidies	0.089	0.137	0.000	0.000	0.000	0.125	0.305
Subsample;	Current receipts like cash flow	0.443	0.258	0.025	0.250	0.500	0.650	0.750
$\text{Inno}_1\text{ExtFin}_1$	Private loans	0.404	0.246	0.125	0.250	0.350	0.550	0.800
N=768	Other internal resources like venture capital or capital increase	0.069	0.150	0.000	0.000	0.000	0.050	0.275
	Subsidies	0.087	0.129	0.000	0.000	0.002	0.150	0.250

2.6.2 Detailed results for the test on the common trend assumption

Table 2.10: Test for the heterogeneity of the treatment effect

	(1) Non-CEM-weighted	(2) CEM-weighted
Dependent variable	ln(Invest)	ln(Invest)
$\text{Inno}_1\text{ExtFin}_0 \times 2005$	0.070	0.027
	(0.165)	(0.169)
$\text{Inno}_1\text{ExtFin}_0 \times 2006$	0.204	0.162
	(0.163)	(0.180)
$\text{Inno}_1\text{ExtFin}_0 \times 2007$	−0.102	−0.182
	(0.198)	(0.203)
$\text{Inno}_1\text{ExtFin}_0 \times 2008$	0.002	−0.112
	(0.185)	(0.189)
$\text{Inno}_1\text{ExtFin}_0 \times 2009$	−0.006	−0.129
	(0.202)	(0.216)
$\text{Inno}_1\text{ExtFin}_0 \times 2010$	0.143	0.065
	(0.205)	(0.221)
$\text{Inno}_1\text{ExtFin}_0 \times 2011$	0.022	0.047
	(0.196)	(0.206)
$\text{Inno}_0\text{ExtFin}_1 \times 2005$	−0.139	−0.216
	(0.163)	(0.182)
$\text{Inno}_0\text{ExtFin}_1 \times 2006$	0.045	0.000
	(0.159)	(1.000)
$\text{Inno}_0\text{ExtFin}_1 \times 2007$	0.130	0.003
	(0.184)	(0.204)
$\text{Inno}_0\text{ExtFin}_1 \times 2008$	−0.132	−0.233
	(0.180)	(0.223)
$\text{Inno}_0\text{ExtFin}_1 \times 2009$	−0.207	−0.347
	(0.193)	(0.258)
$\text{Inno}_0\text{ExtFin}_1 \times 2010$	−0.285	−0.364
	(0.207)	(0.249)
$\text{Inno}_0\text{ExtFin}_1 \times 2011$	−0.348*	−0.412*
	(0.182)	(0.237)

(*continued*)

Table 2.10: *Continued*

	(1) Non-CEM-weighted	(2) CEM-weighted
Dependent variable	ln(Invest)	ln(Invest)
$\text{Inno}_1\text{ExtFin}_1 \times 2005$	0.087	0.050
	(0.167)	(0.171)
$\text{Inno}_1\text{ExtFin}_1 \times 2006$	0.231	0.194
	(0.171)	(0.187)
$\text{Inno}_1\text{ExtFin}_1 \times 2007$	0.241	0.167
	(0.198)	(0.202)
$\text{Inno}_1\text{ExtFin}_1 \times 2008$	0.005	−0.106
	(0.205)	(0.208)
$\text{Inno}_1\text{ExtFin}_1 \times 2009$	−0.432**	−0.550**
	(0.196)	(0.211)
$\text{Inno}_1\text{ExtFin}_1 \times 2010$	−0.394*	−0.469*
	(0.231)	(0.245)
$\text{Inno}_1\text{ExtFin}_1 \times 2011$	−0.472*	−0.441*
	(0.248)	(0.256)
Constant	10.868***	10.765***
	(0.642)	(0.787)
$H_0 : \tau_{1,t} = 0 \ \ \forall \ \ t < 2008$ p-value	0.174	0.197
$H_0 : \tau_{2,t} = 0 \ \ \forall \ \ t < 2008$ p-value	0.449	0.493
$H_0 : \tau_{3,t} = 0 \ \ \forall \ \ t < 2008$ p-value	0.534	0.721
Year fixed effects	Yes	Yes
Firm controls	Yes	Yes
R-squared	0.830	0.837
Observations	3836	3836

Notes: Cluster-robust standard errors in parentheses. Clustered at the firm level. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

2.6.3 Detailed results for the Robustness and sensitivity tests

Table 2.11: Robustness tests concerning alternative method and dependent variable

	(1)	(2)	(3)	(4)	(5)	(6)
	OLS-Regressions		QML-Estimation		Scaled outcome variable	
	Non-CEM weighted	CEM weighted	Non-CEM weighted	CEM weighted	Non-CEM weighted	CEM weighted
Dependent variable	ln(Invest)	ln(Invest)	Invest	Invest	ln(Invest/Sales)	ln(Invest/Sales)
$\text{Inno}_1\text{ExtFin}_0$	0.116	0.090				
	(0.110)	(0.112)				
$\text{Inno}_0\text{ExtFin}_1$	0.330***	0.282**				
	(0.099)	(0.115)				
$\text{Inno}_1\text{ExtFin}_1$	0.407***	0.363***				
	(0.106)	(0.107)				
$\text{Inno}_1\text{ExtFin}_0 \times \text{Crisis}$ (τ_1)	0.037	0.012	−0.345*	−0.398**	0.011	−0.018
	(0.103)	(0.109)	(0.186)	(0.172)	(0.103)	(0.107)
$\text{Inno}_0\text{ExtFin}_1 \times \text{Crisis}$ (τ_2)	−0.198*	−0.203	−0.123	−0.122	−0.201*	−0.234*
	(0.102)	(0.131)	(0.270)	(0.176)	(0.105)	(0.139)
$\text{Inno}_1\text{ExtFin}_1 \times \text{Crisis}$ (τ_3)	−0.414***	−0.445***	−0.315*	−0.419***	−0.417***	−0.452***
	(0.106)	(0.110)	(0.183)	(0.147)	(0.108)	(0.112)
Constant	7.287***	7.115***			−2.964***	−3.154***
	(0.169)	(0.189)			(0.574)	(0.650)
Tests						
$\tau_1 > \tau_2$ p-value	0.017	0.056	0.186	0.068	0.033	0.067
$\tau_1 > \tau_3$ p-value	0.000	0.000	0.419	0.444	0.000	0.000
$\tau_2 > \tau_3$ p-value	0.028	0.039	0.198	0.024	0.036	0.071
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Firm controls	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.664	0.681	-	-	0.517	0.506
Observations	3836	3836	3836	3836	3836	3836

Notes: Cluster-robust standard errors in parentheses. Clustered at the firm level. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level. P-values at the bottom of the table indicate whether to reject H_0 of the following one-sided test: $H_0 : \tau_i \leq \tau_j$ against $H_1 : \tau_i > \tau_j$.

Table 2.12: Robustness tests concerning innovation and external financing measure

	(1)	(2)	(3)	(4)	(5)	(6)
	Inno measure year		Inno measure industry		External financing cut-off at 0.25	
	Non-CEM weighted	CEM weighted	Non-CEM weighted	CEM weighted	Non-CEM weighted	CEM weighted
Dependent variable	ln(Invest)	ln(Invest)	ln(Invest)	ln(Invest)	ln(Invest)	ln(Invest)
$\text{Inno}_1\text{ExtFin}_0 \times \text{Crisis}$ (τ_1)	−0.026	−0.078	−0.036	0.028	−0.049	−0.109
	(0.104)	(0.112)	(0.104)	(0.115)	(0.105)	(0.111)
$\text{Inno}_0\text{ExtFin}_1 \times \text{Crisis}$ (τ_2)	−0.264**	−0.370**	−0.283**	−0.242	−0.219**	−0.314**
	(0.119)	(0.164)	(0.115)	(0.149)	(0.110)	(0.146)
$\text{Inno}_1\text{ExtFin}_1 \times \text{Crisis}$ (τ_3)	−0.395***	−0.395***	−0.420***	−0.434***	−0.386***	−0.449***
	(0.107)	(0.122)	(0.116)	(0.134)	(0.113)	(0.120)
Constant	10.994***	10.891***	11.015***	10.824***	10.966***	10.880***
	(0.642)	(0.777)	(0.648)	(0.791)	(0.654)	(0.795)
Tests						
$\tau_1 > \tau_2$ p-value	0.026	0.035	0.014	0.028	0.079	0.085
$\tau_1 > \tau_3$ p-value	0.000	0.004	0.000	0.000	0.003	0.003
$\tau_2 > \tau_3$p-value	0.147	0.441	0.132	0.110	0.096	0.192
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Firm controls	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.828	0.835	0.828	0.835	0.828	0.835
Observations	3836	3836	3836	3836	3836	3836

Notes: Cluster-robust standard errors in parentheses. Clustered at the firm level. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level. P-values at the bottom of the table indicate whether to reject H_0 of the following one-sided test: $H_0 : \tau_i \leq \tau_j$ against $H_1 : \tau_i > \tau_j$.

Table 2.13: Robustness tests concerning zero investment observations

	(1)	(2)	(3)	(4)	(5)	(6)
	Ad-hoc test		PMM Imputation (1 data set)		PMM Imputation (50 data sets)	
	Non-CEM weighted	CEM weighted	Non-CEM weighted	CEM weighted	Non-CEM weighted	CEM weighted
Dependent variable	ln(Invest)	ln(Invest)	ln(Invest)	ln(Invest)	ln(Invest)	ln(Invest)
$\text{Inno}_1\text{ExtFin}_0 \times \text{Crisis}$ (τ_1)	0.022	−0.035	0.068	0.004	−0.017	−0.048
	(0.099)	(0.112)	(0.104)	(0.114)	(0.109)	(0.116)
$\text{Inno}_0\text{ExtFin}_1 \times \text{Crisis}$ (τ_2)	−0.150	−0.266*	−0.199**	−0.300**	−0.254**	−0.305**
	(0.095)	(0.138)	(0.096)	(0.133)	(0.107)	(0.142)
$\text{Inno}_1\text{ExtFin}_1 \times \text{Crisis}$ (τ_3)	−0.362***	−0.424***	−0.392***	−0.464***	−0.429***	−0.466***
	(0.101)	(0.114)	(0.097)	(0.108)	(0.112)	(0.121)
Constant	10.529***	10.695***	10.495***	10.456***	10.577***	10.671***
	(0.449)	(0.649)	(0.469)	(0.629)	(0.528)	(0.686)
Tests						
$\tau_1 > \tau_2$ p-value	0.057	0.047	0.011	0.015	-	-
$\tau_1 > \tau_3$ p-value	0.000	0.000	0.000	0.000	-	-
$\tau_2 > \tau_3$ p-value	0.027	0.127	0.038	0.112	-	-
$\tau_1 = \tau_2$ p-value	-	-	-	-	0.044	0.074
$\tau_1 = \tau_3$ p-value	-	-	-	-	0.001	0.001
$\tau_2 = \tau_3$ p-value	-	-	-	-	0.138	0.266
Interaction of all variables with zero investment indicator	Yes	Yes	-	-	-	-
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Firm controls	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.972	0.967	0.767	0.789	-	-
Observations	5323	5323	5323	5323	5323	5323

Notes: Cluster-robust standard errors in parentheses. Clustered at the firm level. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level. P-values at the bottom of the table indicate whether to reject H_0 of the following one-sided test: $H_0 : \tau_i \leq \tau_j$ against $H_1 : \tau_i > \tau_j$. For the estimations using multiple imputed data sets in column (5) and (6), we report the p-value for the two-sided test $H_0 : \tau_i = \tau_j$ against $\tau_i \neq \tau_j$, as in Stata in the case of imputed data only the test $\tau_i = \tau_j$ is implemented.

Chapter 3

External financing constraints and firm innovation

Co-authored with Kornelius Kraft

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3.1 Introduction

It is well known that innovation activity is a major determinant of technological progress and of the growth of an economy (Aghion & Howitt 2009; Grossman & Helpman 1994; Solow 1957). Nevertheless, the private spending of innovation-related expenses like R&D is below the socially optimal level (Hall & Lerner 2010). Among other factors, this is rooted in financing constraints driven by the nature of these expenditures, since they provide low collateral, are usually sunk, and are uncertain with respect to outcome and market success. Additionally, innovation expenditures are subject to asymmetric information problems such as adverse selection and moral hazard (Hall 2002). It is empirically shown that internal financing constraints (e.g. Bond et al. 2005; Brown et al. 2012; Harhoff 1998; Hottenrott & Peters 2012), as well as weaker access to external financing (e.g. Czarnitzki & Hottenrott 2011a; Czarnitzki & Hottenrott 2011b), are correlated with lower innovation-related expenses (e.g. R&D). Moreover, studies show that R&D spending is pro-cyclical if firms are credit-constrained during economic downturns (e.g. Aghion et al. 2012; López-Garcia et al. 2013; Ouyang 2011). Nevertheless, there is an ongoing debate (e.g. Hall & Lerner 2010, Kerr & Nanda 2015) regarding the sensitivity of innovation expenditures to bank financing, as external financing is related to many problems that might make this source of financing less relevant for innovation.

A large – but at the same time quite heterogeneous – shock to the banking sector, like the recent financial crisis of 2008/2009, allows us to identify the role of external financing for innovation. We do so by taking account of the specific situation of the banks as their customers' suppliers of debt. The collapse of Lehman Brothers in late 2008 marked the peak in tension on the financial markets during the financial crisis of 2008/2009. After the Lehman bankruptcy, interbank market conditions worsened drastically, with the volume traded on this market reduced and this in turn leading to lower bank lending to the corporate sector (e.g. Ivashina & Scharfstein 2010; Iyer et al. 2014). It has been shown that these lending constraints were transmitted to the real sector, and led to reduced corporate investments and employment (e.g. Campello et al. 2010; Chodorow-Reich 2014; Cingano et al. 2016). In contrast to capital and employment effects, causal evidence on the interaction between the bank system and innovation at firm level during the financial crisis is quite underdeveloped.

The purpose of the paper is to fill this gap by investigating the effects of the financial crisis on innovation activity. Consequently, our identification approach relies on the financial crisis as an unexpected, exogenous and drastic shock on financial markets, which had serious consequences for the lending behavior of banks. We use the fact that the distortion of the interbank market led to heterogeneous shocks to bank lending and in consequence to reductions in real outcomes like capital expenditures (e.g. Cingano et al. 2016). Thus, in order to facilitate identification of the consequences of the crisis for innovation activities, we utilize as a cross-sectional dimension the interbank reliance of banks. We then

estimate the impact of this relative engagement on their corporate customers' innovative activities within a difference-in-differences context. Hence, our aim is not only to identify the specific effect of the financial crisis on innovation activities of the real sector, but also to test for the general impact of external financing on innovation. As we learn more about this relationship when the exogenously determined shock is drastic, the financial crisis is excellently suited for answering an important general question concerning the financing of innovation.

Our main data source is the Mannheim Innovation Panel (MIP), a survey of innovative firms conducted by the Center for European Economic Research (ZEW Mannheim, Germany). The MIP allows us to identify the main bank of each firm. This offers us the opportunity to match the firm data on innovation with information on banks obtained from the Bankscope database compiled by Bureau van Dijk. Using this rich balance sheet data set, an informative indicator for every individual bank's reliance on interbank market transactions before the crisis is computed. Next, the data on the refinancing structure of individual banks is matched with information on their corporate customers, so that we are able to connect individual firm data with the specific involvement of their main bank in the interbank market.

Our difference-in-differences estimates imply that it is indeed more likely that innovation expenditures will be reduced during the crisis if the firm's bank relies heavily on the interbank market. Additionally, we find quite a large reduction in innovation expenditures of about 34.5 percent during the crisis if the firm is related to a bank with an 11.5% higher interbank market reliance than another firm. Moreover, decomposition of total innovation expenditures shows that the effect is stronger on investments in innovation than for current innovation expenditures. We also test for the effect on R&D, with similar results.

Next, we investigate the impact of the crisis on marketing expenditures, a regular firm activity that is largely unrelated to technical progress and much less associated with uncertainty than innovation.[1] However, marketing expenditures serve an important function for firm performance (e.g. Andras & Srinivasan 2003; Erickson & Jacobson 1992) and are related to firm's systematic risk (McAlister et al. 2007). Although it is found that marketing expenditures affects the financial health of firms (Fischer & Himme 2017; Singh et al. 2005), the impact of the availability of external financing for marketing expenditures could be questioned. Testing for the effect of the interbank market shock on marketing expenditures, we find a smaller and only weakly significant effect of the banks' reliance on the interbank market.

Our work is related to a strand of literature which investigates in several different ways the importance of bank financing for firms' innovative activity (e.g. Alessandrini et al. 2010; Amore et al. 2013; Ayyagari et al. 2011; Benfratello et al. 2008; Chava et al. 2013;

[1] See e.g. Malshe & Agarwal (2015) for a discussion of the characteristics of advertising expenditures.

Cornaggia et al. 2015; Hsu et al. 2014). Using a linked firm-bank data set offers a major advantage over studies that rely on the average degree to which banks were affected on a regional level in order to investigate the consequences of financial shocks or changes in regulation on firm behavior in that region (e.g. Amore et al. 2013, Chava et al. 2013; Cornaggia et al. 2015; Nanda & Nicholas 2014). Thus, we do not rely on pooled geographical effects but can base our conclusions concerning the corporate customers' innovation behavior directly on the individual bank-related distress in the financial crisis. Moreover, we use innovation expenditures and R&D as an input-related measure of innovation to determine the effect of a negative shock to the banking system on innovation. This has the advantage of enabling us to identify the immediate effect on the firms and leaves no room for uncertainties concerning the time span between innovation spending and other popular innovation measures such as patenting. Additionally, we extend the existing literature on the effect of external financing constraints on innovation by considering the extensive and intensive margin. Most previously highlighted studies focus on the intensive margin only, although the extensive margin is of interest too (see e.g. Arque-Castells & Mohnen 2015). Furthermore, we add to the above-mentioned strand of literature by analyzing the effects of the negative bank shock on innovation in a bank-based economy during the financial crisis. Exploiting the financing channel, we also contribute to empirical studies that investigate the effects of specific firm characteristics on innovation activity during the financial crisis (e.g.; Archibugi et al. 2013a; Archibugi et al. 2013b; Campello et al. 2010; Filippetti & Archibugi 2011; Paunov 2012).

Moreover, similarly to a very recent work by Huber (2018), we combine bank data with information on their corporate customers. Huber (2018) puts his main emphasis on the impact of the crisis on debt, output, capital, productivity and employment. However, he also considers innovation using patenting as a basis to analyze the persistency of the effects. Our study extends Huber (2018) by computing the effect of the crisis on financial constraints on a broad and representative sample of German banks, whereas he considers a single bank (the Commerzbank) as being affected. Additionally, we develop and use a continuous measure for all banks and the degree to which they were affected by the crisis. This measure is defined as the firm's main bank's interbank market borrowing to assets ratio which varies over the full sample of German banks. Furthermore, we use contemporaneous variables such as total innovation expenditures or R&D – which presumably react very quickly to any financing constraint – whereas patents reflect such an effect only with a considerable time lag, making causality analysis more complicated. Decomposing total innovation expenditures in investments in innovation projects and current innovation expenditures also allows us to draw a more detailed picture than Huber (2018). In addition to the analysis on the firm level, Huber (2018) also conducted an investigation on the county level for the outcome variables GDP, employment and migration. He finds a strong effect of the average Commerzbank dependence of firms in the county. Thus, the county level estimates by Huber (2018) are an alternative way to show that firms

suffer from banks affected by the financial crisis. Both studies point to the importance of external finance for innovation activities.

Our study is structured as follows. Section 3.2 explains the relationship between the financial crisis and the real economy. In the next Section 3.3, data and methodology are explained. Section 3.4 covers the results for the test concerning financial constraints of banks, and the relation to financing problems of innovative activities are presented and discussed. The results of several robustness tests are presented in Section 3.5. The effects on marketing and R&D expenditures are analyzed in Section 3.6. The last Section 3.7 of this chapter comprises our conclusion.

3.2 External innovation financing and the recent financial crisis

We use the effect of the financial crisis as a period of strong disruptions within the financial sector as well as severe problems in the real economy. In such periods, spillovers from turmoil in the financial sector to the real economy are more easily identified than in "normal" times. Moreover, identifying to what extent individual banks are affected by the crisis and thus the addition of a cross-sectional differentiation between the suppliers of debt is particularly helpful for measuring the effects on innovation activity. Following the argumentation of Nanda & Nicholas (2014), this impact on innovation works directly if innovation activity is financed by bank loans. Or it has an indirect effect if the firm has weak access to external funding in general and reallocates internal resources from innovation projects to other, more important activities.

The German banking structure is based on the "three-pillar banking system". Thus, in principle, three kinds of banks can be distinguished: private, cooperative and publicly owned savings banks. Both the cooperative and the public savings banks concentrate on the regional markets where they are located and mostly abstain from investment in international assets.[2] Moreover, their own financing is largely but not solely based on deposits. Deposits do not usually fluctuate much and during the financial crisis they remained fairly stable (e.g. Cornett et al. 2011). Private banks pursue a quite different business model as they are engaged in international investment and source liquidity to a significant degree through resources other than core deposits.

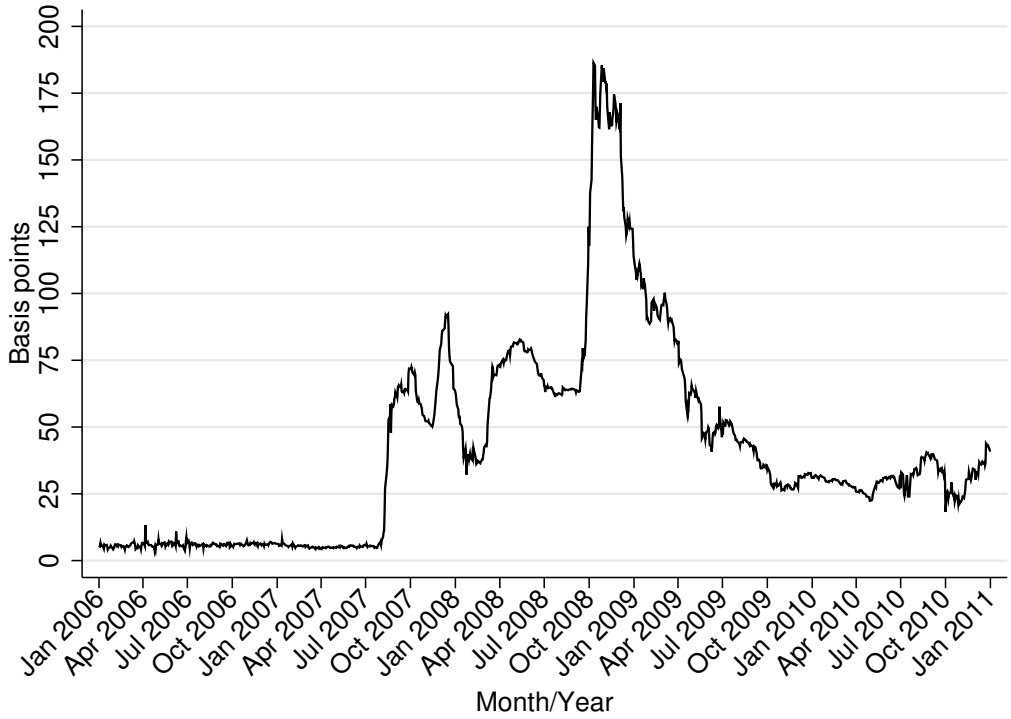
Following the description in Bräuning & Fecht (2016), there are two markets for bank liquidity in the Eurozone. First, the primary markets, in which banks borrow money from the European Central Bank against collateral through open market operations. Second,

[2]Both pillars mentioned are two-tier systems themselves. Besides regional savings banks in the public banks pillar, Landesbanken serve as central institutions and are responsible for capital market transactions and refinancing at wholesale funding markets. The same holds for the cooperative bank pillar, where cooperative central banks also exist with functions similar to Landesbanken.

the interbank market, which plays a crucial role in the financial system by redistributing liquid assets among banks. Banks with a surplus of liquid assets, but also those with a lack of liquidity, use the interbank market to exchange financial resources by secured or unsecured lending. As argued in Bräuning & Fecht (2016), unsecured lending is preferred in normal times since there is no need for costly collateral and interest rates.

Consequently, a shock in the banking system that affects the interbank market negatively has severe consequences for liquidity provision and the cost of funds. If there is no immediate possibility to compensate the deficit through other sources of financing, banks are more likely to use liquidity for internal purposes than for loan supply (e.g. Cornett et al. 2011). Strains on the interbank market are exemplified by the spread between the European interbank interest rate and the overnight risk-free swap rate. The difference between the 3-month Euro InterBank Offered Rate (EURIBOR) and the 3-month Euro OverNight Index Average (EONIA) rates are shown in Figure 3.1. The emerging tensions on the interbank market in mid-2007 are reflected in the rise of the EURIBOR-EONIA spread. The spread reached its height in October 2008, immediately after the collapse of Lehman Brothers. Thus, following the insolvency of the Lehman Brothers bank in September 2008, the interbank market almost dried up.

Figure 3.1: 3-Month EURIBOR-EONIA Spread



Note: Source: German Federal Bank (own calculations).

Distress on the interbank market in the recent financial crisis resulted in liquidity hoarding and a loss in trust among banks (Acharya & Merrouche 2012; Acharya & Skeie 2011; Ashcraft et al. 2011). As a consequence of hoarding and a re-shifting of liquidity, banks

reduced their loan supply or applied less favorable credit conditions (Cingano et al. 2016; Ivashina & Scharfstein 2010; Iyer et al. 2014; Kapan & Minoiu 2018).

This particular reduction in lending is also reported for Germany. Craig & Von Peter (2014) show that lending volumes in the German interbank market indeed went down. This in turn led to reduced lending by banks engaged in refinancing by interbank loans (Bundesbank 2009; IMF 2016). Additional evidence comes from Puri et al. (2011), who investigated the lending behavior of public savings banks related to an affected Landesbank. They show that these types of banks reduced their lending following the crisis to a stronger degree than savings banks related to an unaffected Landesbank.

Our identification strategy relies on the interbank involvement of a firm's main bank. More severely affected banks have a higher degree of interbank market borrowing and will in turn reduce their lending supply more strongly. Innovative firms in particular will find it difficult to obtain external finance if financial markets are under stress (Lee et al. 2015; North et al. 2013), as capital market imperfections due to asymmetric information likewise grow more severe during a negative shock to the bank system.[3] Firms might try to find substitutes like equity financing (Kahle & Stulz 2013), but this is likely to be rather difficult during such major turmoil on the financial markets (e.g. Iyer et al. 2014; Kahle & Stulz 2013). Consequently, firms which are related to a bank that is engaged to a larger extent in interbank market borrowing will reduce their innovation spending in the financial crisis due to external financing constraints.

3.3 Data and methodology

3.3.1 Database and variables

To test for the effect of the financial crisis on innovation and the degree of interbank market usage of banks, we combine firm data with bank balance sheet data for their corporate main bank. The firm information is based on the Mannheim Innovation Panel (MIP), which represents the German section of the European CIS Survey. Our sample consists of 3493 non-financial firms for which we have firm information as well as a bank identifier. The sampled firms stem from the manufacturing industry (NACE Rev. 2.0 divisions 5 to 39) and the knowledge-intensive services (NACE Rev. 2.0 divisions 58 to 66 and 69 to 73). These are more or less all of the firms available in the MIP excluding firms which operate in non-knowledge-intensive service industries.[4] Appendix 3.8.1, Table 3.8 shows the quite homogeneous distribution of firms over the industries. To investigate

[3] Among others, Freel (2007) and Mina et al. (2013) show that innovators have problems in accessing external financing even in normal times.

[4] Innovative activity of knowledge-intensive services and their contribution to economic growth was highlighted by Barras (1986). Moreover, Barras (1986), Freel (2006), Gallouj & Weinstein (1997) as well as Tether (2005) further characterize innovation activity in the knowledge-intensive service industries.

the innovation behavior of firms in the financial crisis, we employ the periods from 2005 to 2010 which cover three periods before and during the crisis. Table 3.10 in Appendix 3.8.1 shows that roughly half of the firms are observed once in the sample period while the remaining quarters are observed either twice or more than twice.

We are able to identify the 686 individual main banks[5] with which firms have commercial relations. The main bank plays a distinct role if a firm has relations to several banks. Among other characteristics, this is rooted in the fact that the main bank is regarded as primary lender (Elsas & Krahnen 1998) and serves as the first point of contact when it comes to distress of the firm (Edwards & Fischer 1996). Information available on the individual firm level is matched with data on their banks with respect to interbank borrowing. All data on banks originates from the Bankscope database, which is compiled by Bureau van Dijk. This matching offers us the opportunity to identify the possible mechanism of how shocks incurred by banks were transmitted to their clients.[6]

We use the log of total innovation expenditures 'Log of Total innovation expenditures'[7] as outcome variable to investigate the effect of the degree of bank stress on corporate innovation activity.[8] We are able to decompose total innovation expenditures into investments in innovation projects and current innovation expenditures, which results in two additional dependent variables that are the logarithms of both expenses: 'Log of Investments in innovation projects' and 'Log of Current innovation expenditures'. We calculate the value of current innovation costs as the difference between total innovation expenditures and investments in innovation projects. Investment in innovation projects covers expenditures for additional investment and tangible assets for the purpose of innovation. Current innovation costs cover the rest of the total innovation expenditures, for example expenses for personnel, material and external knowledge. Thus, investments in innovation projects are to some degree more tangible and flexible compared to current innovation costs. Therefore, we expect that it is somewhat easier to obtain external financing for investment than for the other types of expenditure. Consequently, investment will also be more strongly affected if the customer's bank gets into trouble during the crisis. Furthermore, other expenditures include to a large degree outlay for highly qualified researchers. These employees have high general and also firm-specific human capital and will probably not be dismissed if the crisis is expected to be temporary. In Section 3.6 we will also

[5]Some firms have relations to more than just one bank. Similar to our approach De Bonis et al. (2015); Djankov et al. (2005); Höwer (2016) also focus on the impact of just the main bank on firm behavior.

[6]In the case of private banks, we use the balance sheet data for the head bank if the firm was affiliated to a branch of the specific bank. In 2009, Dresdner Bank merged with Commerzbank. Since we do not want to create a selection problem by dropping those observations, we cope with their merger by using the mean of both banks' 2006 interbank values. In addition, in our sample, the interbank borrowing to asset values for Dresdner bank (0.376) and Commerzbank (0.388) are close together.

[7]To account for the zero values, we log transform the variable as ln(expense+1).

[8]Total innovation expenditures are quite broadly defined and the MIP characterizes total innovation expenditures as expenditures for (internal) R&D, expenditures for acquisition of external knowledge (licenses, external R&D), expenditures for product design and production preparation related to innovation, expenditures for market tests and market introductions, retraining of personnel, additional investment and material for the purpose of innovation.

report results on R&D, as this is a standard variable in the context of innovation. R&D is obviously more narrowly defined than total innovation expenditures, but we expect in principle a similar effect of bank constraints on R&D. Due to the similarities in the composition of the expenses, the effect on R&D might be similar in terms of size compared to current innovation costs.

The MIP also allows the use of common variables to explain the innovation expenditures of firms. We use lagged values of the logarithm of employees 'Log of Employees' to capture the effect of firm size. Moreover, we control for possible age effects by including the variable 'Log of Firm age'. To control for the effect of belonging to a group of firms, we include a dummy 'Part of firm group' which assumes unit value if the firm is part of a group and 0 if not. Additionally, we include industry and federal state fixed effects.[9]

As an alternative to the availability of internal means we utilize the lagged value of the firm's credit rating 'Firm rating'. The rating index is calculated by Creditreform, the largest German credit rating agency. It is constructed from several qualitative (e.g. organizational structures, management quality) and quantitative (e.g. liquidity, capital structure) factors and ranges from 100 (best rating) to 600 (worst rating).[10] A higher rating is associated with a higher probability of default by the firm. Clearly, in all likelihood, access to external finance is limited in the case of a weak rating since banks interpret this as a negative signal. A weak (high value in our case) rating evaluation can also be interpreted as insufficient availability of internal means. This in turn will probably have a negative effect on innovation expenditures. In addition, the lagged growth of sales volume 'Sales growth' is included. This variable is interpreted by Behr et al. (2013) as a proxy variable for Tobin's Q and therefore growth and investment opportunities. Moreover, we include the lagged share of exports in total sales 'Export share' as a proxy for demand-related shocks. As we cannot rule out the possibility that missing values might bias our results, we impute missing values for the variables 'Lagged sales growth' (1148 values) and 'Lagged export share' (929 values) by predictive mean matching following Rubin (1976).

Furthermore, matching with the Bankscope database allows us to employ additional variables to account for bank characteristics. To evaluate the banks' involvement in the interbank market and their influence on the firms' financing during the crisis, the following variable is computed: the ratio of interbank market borrowing to total assets (Interbank) in percent for firm i's main bank j. The measure is based on data from 2006 to take account of banks' pre-crisis reliance on interbank borrowing. Additionally, we use the following bank variables. These are the number of banks a firm is related to 'Number of banks', bank size measured in the logarithm of bank assets 'Log of Bank assets' and return on average assets 'Return on bank assets'. Descriptive statistics for our sample are

[9] See Tables 3.8 and 3.9 in Appendix 3.8.1 for the distribution of firms over industries and federal states.
[10] See Czarnitzki & Hottenrott (2011a) for a detailed description of the rating index and its construction.

given in Table 3.1.

Table 3.1: Descriptive statistics

	N	Mean	SD	P10	P25	Median	P75	P90
Dependent variables								
Log of Total innovation expenditures	6945	11.298	5.170	0.000	10.980	12.877	14.336	15.642
Log of Investments in innovation projects	6945	9.146	5.546	0.000	5.281	11.316	12.877	14.486
Log of Current innovation expenditures	6945	10.184	5.610	0.000	9.658	12.184	13.793	15.179
Log of R&D expenditures	6252	9.604	5.757	0.000	8.272	11.896	13.465	14.956
Log of Marketing expenditures	4350	10.762	3.653	8.272	9.881	11.267	12.857	14.375
Firm controls								
Log of Employees	6945	4.061	1.556	2.197	2.890	3.932	5.017	6.118
Log of Firm Age	6945	2.997	0.855	1.946	2.485	2.890	3.497	4.263
Part of firm group	6945	0.474	0.499	0.000	0.000	0.000	1.000	1.000
Firm rating	6945	220.695	47.223	170.000	195.000	218.000	246.000	272.000
Sales growth	6945	0.057	0.233	−0.200	−0.056	0.042	0.140	0.289
Export share	6945	0.235	0.264	0.000	0.001	0.123	0.412	0.657
Bank variables								
Interbank	6945	0.261	0.115	0.091	0.155	0.314	0.374	0.382
Number of banks	6945	2.235	1.252	1.000	1.000	2.000	3.000	4.000
Log of Bank assets	6945	24.151	2.987	20.296	21.355	23.801	26.613	28.003
Return on assets	6945	0.112	0.469	−0.110	0.060	0.160	0.260	0.360

Note: Count for the R&D expenses variable is 6252, for the Marketing expenses variable 4350.

Next, we discretize our interbank measure. This allows us to construct the treatment and control groups usually utilized in the difference-in-differences context. To do so, we sort firms that are related to a bank with an interbank value in the upper decile of the distribution into the treatment group.[11] The resulting treatment group covers 3610 firm-year observations while the control group consists of 3335 firm-year observations. Results for the comparison of firm covariates for treatment and control group are given in Table 3.11, Appendix 3.8.1. Obviously, firms that are related to a bank in the treatment group are larger, more likely to be part of a firm group and will probably export more.

Table 3.2, Panel A shows the differences in the main outcome variables for the treatment and control group in the period before the crisis and after the crisis. The treatment group has a higher mean of innovation expenses pre-crisis as well as during the crisis period. Nevertheless, Columns (5) and (6) imply that the difference in means of the variables between the crisis and pre-crisis period is larger for the treatment group. This observation is also reflected in the difference-in-differences in Column (7). Compared to the control group, the treatment group has reduced its spending of both types of expenditure to a larger extent during the crisis than in the period before. This decline is reflected in the quite large reduction in total innovation expenditures of about 40%, in investments in innovation projects of around 42% and in current innovation expenses of about 37%.[12]

To also determine the general innovative pattern of the firms in our sample, we generate three additional variables from our continuous outcome variables of interest. The indicator variables with the prefix 'Non-Zero' take unit value if the firm reports a positive value, larger than zero for the expense in question and zero otherwise. From Table 3.2, Panel B, it becomes evident that a large number of the firms are innovative in a sense that their innovation expenses are above zero. As given in Column (5), the control group shows no change in reporting zero innovation expense of either type in the crisis. The picture changes for the treatment group in Column (6). Apparently, the firms belonging to the treatment group are more likely to report zero values during the crisis period. The difference-in-differences estimates in the last Column (7) imply that, compared to the control group, firms belonging to the treatment group are more likely to report zero expenses of either type due to the crisis. That is, treated firms are 3.8% more likely to report zero total innovation expenditures, 4.6% more likely to report zero investments in innovation and 3.3% more likely to report zero current innovation expenditures.[13] These

[11] See Figure 3.2 in Appendix 3.8.1 for a plot of the ordered values of the Interbank variable. Moreover, Figure 3.3 in Appendix 3.8.1 shows a kernel density plot with a vertical line at an Interbank value of 0.308 indicating the cut-off point to the upper 10% of the Interbank values. See Table 3.12 in Appendix 3.8.2 for results with redefined treatment and control groups. To obtain the results in this table, the treatment group consists of firms related to a bank in the upper 25% of the interbank measure and the control group of firms related to the lower 75%. Descriptive statistics for these groups are shown in Table 3.13.

[12] Following the literature (e.g. Giles 1982; Halvorsen and Palmquist 1980; van Garderen and Shah 2002), the percentage change of a dummy variable in a semilogarithmic estimation is calculated as $100(exp(\beta)-1)$. See Table 3.14 in Appendix 3.8.2 for a determination of these effects when conditioning on additional control variables.

[13] Following the literature (e.g. Giles 1982; Halvorsen & Palmquist 1980; van Garderen & Shah 2002), the percentage change of a dummy variable in a semilogarithmic estimation is calculated as $100(exp(\beta)-1)$.

effects are quite small compared to the absolute reduction determined in Panel A of Table 3.2.

See Table 3.14 in Appendix 3.8.2 for a determination of these effects when conditioning on additional control variables.

Table 3.2: Difference in outcome variables for treatment and control group

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Mean				Difference		
	Pre-Crisis		Crisis				
	Control	Treatment	Control	Treatment	(3)-(1)	(4)-(2)	(6)-(5)
Panel A: Continuous outcome variables							
Log of Total innovation expenditures	10.701	12.122	10.693	11.600	−0.008	−0.522***	−0.514**
					(0.963)	(0.002)	(0.038)
Log of Investments in innovation projects	9.039	9.970	8.603	8.994	−0.436**	−0.976***	−0.540**
					(0.020)	(0.000)	(0.043)
Log of Current innovation expenditures	9.538	11.246	9.317	10.561	−0.222	−0.685***	−0.463*
					(0.255)	(0.000)	(0.084)
Panel B: Binary outcome variables							
Non-Zero Total innovation expenditures	0.822	0.874	0.834	0.847	0.012	−0.027**	−0.039**
					(0.376)	(0.020)	(0.027)
Non-Zero Investments in innovation projects	0.758	0.795	0.733	0.723	−0.025*	−0.072***	−0.047**
					(0.099)	(0.000)	(0.022)
Non-Zero Current innovation expenditures	0.761	0.836	0.752	0.793	−0.009	−0.043***	−0.034*
					(0.532)	(0.001)	(0.085)

Notes: The treatment group consists of firms which are related to a bank in the upper 10% of the interbank distribution. Firms in the control group are associated with a bank in the lower 90% of the interbank distribution. For the differences in columns (5) - (7) p-values are given in parentheses. Column (7) shows difference-in-differences results. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

3.3.2 Methodology

We employ the difference-in-differences estimation method to test for the hypothesis that firms related to a bank that is more reliant on interbank market borrowing reduce their innovation-related expenditures to a higher degree during the financial crisis. This estimation strategy has two advantages: First, we are able to control for common effects (i.e. macroeconomic conditions). Moreover, we are able to account for unobserved, time-invariant effects. We have repeated cross-sections for multiple consecutive years available and apply a variant of the standard difference-in-differences model, suggested by Imbens & Wooldridge (2009) with a continuous treatment variable:

$$\ln(y_{it}) = \beta_0 + \beta_1 \text{Interbank}_{ij} + \tau_1 \text{Interbank}_{ij} \times \text{Crisis}_t + \beta_m X_m + \rho_i + \eta_i + \pi_t + \varepsilon_{it} \quad (3.1)$$

whereby the dependent variable is the natural logarithm of the innovation-related expenses described above. Interbank reflects the interbank market borrowing ratio to total assets of the firm's main bank as of 2006. Hence, we use a variant of the well-known difference-in-differences model by taking account of the treatment intensity. Similar empirical models have been applied by Acemoglu et al. (2004), Duchin et al. (2010) and Waldinger (2010). Basically, it is assumed that the effect of the treatment variable is stronger if the value of this variable increases. The similarity to the usual difference-in-differences model is that the treatment variable enters the equation twice: first unchanged and then interacted with the relevant treatment period, in our case the time of the crisis. Thus, the interaction variable Interbank×Crisis takes the value of the interbank market borrowing to asset ratio if the year is 2008 and later, and is zero for all years before 2008. Its coefficient informs us about the impact of the firms' main bank reliance on interbank market borrowing on the specific expenditures due to the crisis. It is quite likely that banks with a higher interbank borrowing ratio face greater problems during the crisis. We therefore expect a negative coefficient of the interaction term. The vector of firm-specific regressors is represented by X_m and β_m stands for the coefficients to be estimated. To control for industry-specific differences, we include industry-fixed effects ρ_i. In addition, year (π_t) as well as federal state (η_i) fixed effects are included. The random error is denoted as ε_{it}.

To account for possible corner solutions, we apply the Tobit estimation technique. As Wald tests reject the assumption of homoscedasticity, we consider heteroscedastic Tobit models. We consider groupwise multiplicative heteroscedasticity using a set of three firm-size dummies based on the number of employees as well as dummies for age and industries.[14] Utilizing Tobit models, we also analyze both the extensive and the intensive margin (see e.g. Arque-Castells & Mohnen 2015). Thus, we not only concentrate

[14]The results are quite robust to the choice of variables of the heteroscedasticity term, as long as firm size, age and industry association are included. See Appendix 3.8.3, Table 3.15 for the results when changing the variables in the heteroscedasticity term.

on the change in innovation expenses in terms of size (intensive margin) but also on the probability of spending any amount on innovation (extensive margin).

3.4 Empirical results

Regression results for Equation (3.1) are shown in Table 3.3.[15] In the context of our research question, the most important variable is the treatment variable multiplied by the crisis indicator Interbank×Crisis. The coefficient of this variable is negative in each regression and significant at least at the 5 percent level. This means that, if firms are associated with a main bank which has a higher interbank market borrowing-to-assets ratio, they reduce their innovation expenditures of either type during the crisis (in comparison to observations with a lower interbank market borrowing-to-assets ratio). The effect is quite large, as a firm with a main bank that has a one standard deviation higher interbank market value than another firm reduces the innovation expenditures by about 34,5% due to the crisis.[16] In comparison to current innovation expenditures, the coefficients are larger (albeit not significantly different) if investment is considered. This is in line with our expectations outlined above. Moreover, firms which are related to a bank that has a one standard deviation higher interbank market borrowing ratio are about 0.46 percent less likely to report a non-zero value of total innovation expense.[17]

For the control variables, we observe the following: Variables capturing the effects of size and age show the expected signs and are highly significant. In addition, the proxy for the business conditions with respect to internal resources and access to external financing (Firm rating) is negative and significant at least at the 5 percent level. This indicates that firms with a weak rating (high value) have lower innovation expenditures than better rated firms. This could be rooted in the fact that they have less internal means available or face problems in accessing external capital due to their weak rating.

Next, we test whether there was a significant difference in investment behavior prior to the first crisis year, 2008. This serves as a test for the common trend assumption following the methodology proposed by Mora & Reggio (2015). Thus, we interact the interbank borrowing ratio with the full set of year dummies except for the dummy for 2005, which serves as our basis year. We test the null on common pre-treatment trends

[15] Table 3.16 in Appendix 3.8.3 covers results of estimations for Equation (3.1) for alternative models (including OLS and a homoscedastic Tobit model). Moreover, Table 3.17 of Appendix 3.8.3 covers estimation results for a fixed effects Poisson quasi-maximum likelihood estimator (see e.g. Wooldridge 1999a; Wooldridge 1999b).

[16] Huber (2018) also estimates a large impact of the crisis for his sample. He finds a 55% reduction in the number of patents during the financial crisis for a firm which is fully related to the Commerzbank and has already patented in the years 1990 to 2004.

[17] See Figures 3.4, 3.5 and 3.6 in Appendix 3.8.4 for a graphical illustration of the treatment effects over the distribution of the Interbank measure. The figures show the effect of a marginal change in the Interbank measure (i.e. 1%) at each value of the Interbank distribution. The figures imply that the treatment effect shows a small variation over the distribution of the Interbank variable. While the marginal effects for the intensive margin increase over the distribution, the marginal effects for the extensive margin decrease.

H_0: $\tau_t = 0 \quad \forall \quad t \leq 2007$ simultaneously.[18] The parallel trend assumption would be met if we do not reject H_0 at the ten percent level. The results at the bottom of Table 3.3 reveal that the coefficients of the pre-crisis interactions are not significantly different from each other. Thus, the common trends assumption is met for each outcome. Detailed estimation results are shown in Table 3.18 of Appendix 3.8.4. Inspection of the effect of heterogeneity in Table 3.19 of Appendix 3.8.4 implies that it is heterogeneous over time and was strongest in 2009. Nevertheless, the p-values at the bottom of the table show that coefficients of the interaction terms are not different from each other in the treatment period.

The results in Table 3.3 clearly show that firms related to a bank that is more engaged in interbank market borrowing reduce innovation expenditure to a larger extent. Distinguishing between the extensive and intensive margin, we observe the following: Even when the reduction in terms of expenditure size is high, the reduction in probability of having non-zero expenditure is low. Summarizing, banks' involvement in interbank markets with consequent refinancing problems have sizeable effects on the innovation activities of their corporate customers. This shows the relevance of external financing for innovation. Although the basic characteristics of innovation activities (i.e. low collateral, asymmetric information problems and general uncertainty with respect to economic outcome) justify doubts as to whether a connection between debt financing and innovation exists at all, our results imply that firms' innovation behavior is sensitive to bank financing.

[18] See e.g. Hangoma et al. (2018) and Yamamura (2016) for recent papers applying a similar approach.

Table 3.3: Determinants of innovation expenditures including the continuous Interbank measure

Dependent variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Log of Total innovation expenditures			Log of Investments in innovation projects			Log of Current innovation expenditures		
	Tobit	Intensive	Extensive	Tobit	Intensive	Extensive	Tobit	Intensive	Extensive
Interbank	1.656*	1.418*	0.021*	0.273	0.193	0.007	2.236**	1.715**	0.045*
	(0.987)	(0.845)	(0.013)	(1.177)	(0.830)	(0.031)	(1.136)	(0.871)	(0.023)
Interbank × Crisis	−3.499***	−2.995***	−0.044***	−4.009***	−2.827***	−0.104***	−3.756***	−2.881***	−0.075***
	(1.101)	(0.940)	(0.015)	(1.408)	(0.991)	(0.037)	(1.325)	(1.013)	(0.027)
Log of Employees	1.081***	0.925***	0.014***	1.052***	0.742***	0.027***	1.329***	1.019***	0.026***
	(0.068)	(0.058)	(0.001)	(0.096)	(0.068)	(0.003)	(0.077)	(0.058)	(0.002)
Log of Firm Age	−0.415***	−0.355***	−0.005***	−0.411***	−0.290***	−0.011***	−0.379***	−0.291***	−0.008***
	(0.111)	(0.095)	(0.001)	(0.150)	(0.105)	(0.004)	(0.126)	(0.096)	(0.003)
Part of firm group	0.267	0.229	0.003	0.148	0.104	0.004	0.331	0.254	0.007
	(0.191)	(0.164)	(0.002)	(0.243)	(0.171)	(0.006)	(0.221)	(0.169)	(0.004)
Firm rating	−0.005**	−0.004**	0.000**	−0.006**	−0.004**	0.000**	−0.006***	−0.005***	0.000**
	(0.002)	(0.002)	(0.000)	(0.003)	(0.002)	(0.000)	(0.002)	(0.002)	(0.000)
Sales growth	0.445*	0.381*	0.006*	0.575	0.405	0.015	0.373	0.286	0.007
	(0.268)	(0.229)	(0.003)	(0.355)	(0.250)	(0.009)	(0.315)	(0.242)	(0.006)
Export share	2.285***	1.956***	0.029***	2.064***	1.456***	0.054***	2.739***	2.101***	0.055***
	(0.306)	(0.260)	(0.004)	(0.409)	(0.286)	(0.011)	(0.358)	(0.273)	(0.008)
Constant	6.744***			5.526***			2.756**		
	(1.162)			(1.534)			(1.363)		
H_0: common pre-treatment trends									
$\chi^2_{(1)}$	1.588	1.589	1.570	0.477	0.477	0.477	2.193	2.196	2.171
p-value	0.452	0.452	0.456	0.788	0.788	0.788	0.334	0.334	0.338
Industry fixed effects	Yes			Yes			Yes		
Year fixed effects	Yes			Yes			Yes		
Federal state fixed effects	Yes			Yes			Yes		
Log likelihood	-19348.869			-19020.349			-19141.567		
Left-censored observations	1077			1726			1486		
Uncensored observations	5868			5219			5459		
Observations	6945			6945			6945		

Notes: Standard errors clustered by firm are reported in parentheses. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

3.5 Robustness tests

3.5.1 Adding bank variables

As a first robustness test, we extend our specification by including variables on important bank characteristics, since otherwise the problem of an omitted variable bias might be present. Thus, we add three variables which might be correlated with the access of firms to bank financing and the individual banks' ability to supply loans. First, we include the lagged number of banks a firm is affiliated to. Even if the main bank serves as the predominant supplier of external funding, we cannot exclude the possibility that other banks also play a role in this connection. To test for such a possible effect, we take into account the lagged logarithm of bank assets as a measure for bank size which is commonly used in the literature. As a measure for the profitability of the bank, we add the return on average assets as reported by Bankscope.

Results for the extended specification are shown in Table 3.4. The added bank variables do not exert an effect on innovation spending that is significantly different from zero. Interestingly, the coefficient for the interbank borrowing-to-assets ratio became insignificant in each regression. This might indicate that the added variables are correlated with the interbank measure. Nevertheless, the results for the interaction terms do not change to a large extent in terms of size and significance.

Table 3.4: Determinants of innovation expenditures including variables on bank characteristics

Dependent variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Log of Total innovation expenditures			Log of Investments in innovation projects			Log of Current innovation expenditures		
	Tobit	Intensive	Extensive	Tobit	Intensive	Extensive	Tobit	Intensive	Extensive
Interbank	1.488	1.274	0.019	0.740	0.522	0.019	1.484	1.138	0.030
	(1.175)	(1.005)	(0.015)	(1.491)	(1.051)	(0.039)	(1.361)	(1.043)	(0.027)
Interbank × Crisis	−3.501***	−2.997***	−0.044***	−3.833***	−2.703***	−0.100***	−3.936***	−3.019***	−0.078***
	(1.119)	(0.955)	(0.015)	(1.422)	(1.000)	(0.037)	(1.357)	(1.037)	(0.028)
Log of Employees	1.066***	0.912***	0.014***	1.038***	0.732***	0.027***	1.313***	1.007***	0.026***
	(0.072)	(0.061)	(0.001)	(0.098)	(0.070)	(0.003)	(0.081)	(0.061)	(0.002)
Log of Firm age	−0.434***	−0.371***	−0.006***	−0.441***	−0.311***	−0.011***	−0.387***	−0.297***	−0.008***
	(0.114)	(0.097)	(0.001)	(0.152)	(0.107)	(0.004)	(0.128)	(0.098)	(0.003)
Part of firm group	0.270	0.231	0.003	0.166	0.117	0.004	0.319	0.245	0.006
	(0.192)	(0.165)	(0.002)	(0.244)	(0.172)	(0.006)	(0.222)	(0.170)	(0.004)
Firm rating	−0.005**	−0.004**	0.000**	−0.006**	−0.004**	0.000**	−0.006**	−0.005**	0.000**
	(0.002)	(0.002)	(0.000)	(0.003)	(0.002)	(0.000)	(0.002)	(0.002)	(0.000)
Sales growth	0.455*	0.389*	0.006*	0.582	0.411	0.015	0.381	0.292	0.008
	(0.267)	(0.229)	(0.003)	(0.355)	(0.250)	(0.009)	(0.314)	(0.241)	(0.006)
Export share	2.264***	1.938***	0.029***	2.055***	1.449***	0.054***	2.706***	2.075***	0.054***
	(0.309)	(0.263)	(0.004)	(0.413)	(0.289)	(0.011)	(0.362)	(0.275)	(0.008)
Number of banks	0.054	0.046	0.001	0.075	0.053	0.002	0.027	0.021	0.001
	(0.071)	(0.061)	(0.001)	(0.101)	(0.072)	(0.003)	(0.080)	(0.062)	(0.002)
Log of bank size	0.009	0.008	0.000	−0.023	−0.016	−0.001	0.039	0.030	0.001
	(0.041)	(0.035)	(0.001)	(0.053)	(0.038)	(0.001)	(0.046)	(0.035)	(0.001)
Return on bank assets	−0.012	−0.010	0.000	0.133	0.094	0.003	−0.146	−0.112	−0.003
	(0.154)	(0.132)	(0.002)	(0.205)	(0.145)	(0.005)	(0.185)	(0.142)	(0.004)
Constant	6.531***			5.834***			2.086		
	(1.373)			(1.812)			(1.586)		
Industry fixed effects	Yes			Yes			Yes		
Year fixed effects	Yes			Yes			Yes		
Federal state fixed effects	Yes			Yes			Yes		
Log likelihood	-19348.375			-19019.469			-19140.524		
Left-censored observations	1077			1726			1486		
Uncensored observations	5868			5219			5459		
Observations	6945			6945			6945		

Notes: Standard errors clustered by firm are reported in parentheses. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

3.5.2 Bank switcher

Up to now we have implicitly assumed that banks and firms match randomly. We first test whether switching the main bank plays a role regarding the estimated effect. Long-term firm-bank relationships are advantageous for firms with respect to collateral requirements (Berger & Udell 1995; Boot 2000; Harhoff & Körting 1998) and credit supply (Elsas & Krahnen 1998; Stephan et al. 2012). Switching during the crisis may occur as the previous bank encountered problems and the new one was not affected by the crisis. In such a scenario, switching may improve the situation of the customer. Nevertheless, studies have shown that switching the main bank leads to uncertainties with respect to borrower quality (Sharpe 1990) and could lead to less favorable loan conditions or denial of credit (Rajan 1992; Sharpe 1990; Stephan et al. 2012). The availability of information on the main bank relation over time also allows us to identify which firms switched their main banks.

As shown in Table 3.20 in Appendix 3.8.5, we find that about 3 to 4 percent of the firms switch their main bank each year. Moreover, considering the interbank market borrowing ratio, we find that the firms do not systematically switch to banks with higher or lower interbank borrowing-to-assets ratios. Results for the sample of firms that did not switch their main bank during the entire period are shown in Table 3.5, Panel A. The effect is lower when compared to Table 3.3, which points towards an advantage arising from the long-standing relationship. Nevertheless, the effect is not different from the estimates presented in Table 3.3 in terms of significance. Thus, we conclude that neither switching the main bank nor the opposite affected our estimates substantially. We also test whether missing values in the bank account history significantly affect our results as these firms might have also switched their main bank. Thus, we also drop those observations in addition to the bank-switching firms. The results in Panel B of Table 3.5 imply that the effects are fairly similar to those estimated in Table 3.3. Consequently, we find that switching the main bank does not affect our results.

Table 3.5: Determinants of innovation expenditures based on the sample without bank-switching firms

Dependent variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Log of Total innovation expenditures			Log of Investments in innovation projects			Log of Current innovation expenditures		
	Tobit	Intensive	Extensive	Tobit	Intensive	Extensive	Tobit	Intensive	Extensive
Panel A: Sample without firms switching their banks									
Interbank	1.690*	1.450*	0.021*	0.188	0.133	0.005	2.237*	1.729*	0.043*
	(1.015)	(0.871)	(0.013)	(1.258)	(0.894)	(0.032)	(1.203)	(0.929)	(0.023)
Interbank × Crisis	−2.849**	−2.444**	−0.035**	−3.363**	−2.389**	−0.086**	−2.933**	−2.267**	−0.056**
	(1.143)	(0.979)	(0.015)	(1.532)	(1.087)	(0.040)	(1.409)	(1.087)	(0.027)
Constant	6.656***			5.086***			2.891**		
	(1.204)			(1.595)			(1.431)		
Industry fixed effects	Yes			Yes			Yes		
Year fixed effects	Yes			Yes			Yes		
Federal state fixed effects	Yes			Yes			Yes		
Firm controls	Yes			Yes			Yes		
Log likelihood	-15615.251			-15458.020			-15485.228		
Left-censored observations	856			1384			1186		
Uncensored observations	4791			4263			4461		
Observations	5647			5647			5647		

(*continued*)

Table 3.5: *Continued*

Dependent variable	(1) Log of Total innovation expenditures			(4) Log of Investments in innovation projects			(7) Log of Current innovation expenditures		
	Tobit	Intensive	Extensive	Tobit	Intensive	Extensive	Tobit	Intensive	Extensive
Panel B: Sample without firms switching their banks and without firms with incomplete bank account history									
Interbank	2.110**	1.805**	0.026**	0.777	0.555	0.020	2.589**	2.007**	0.049**
	(1.032)	(0.882)	(0.013)	(1.286)	(0.919)	(0.032)	(1.226)	(0.949)	(0.023)
Interbank × Crisis	−3.563***	−3.049***	−0.045***	−3.971**	−2.837**	−0.100**	−3.496**	−2.710**	−0.066**
	(1.175)	(1.002)	(0.015)	(1.586)	(1.130)	(0.040)	(1.461)	(1.130)	(0.028)
Constant	6.156***			4.898***			2.730*		
	(1.220)			(1.652)			(1.453)		
Industry fixed effects	Yes			Yes			Yes		
Year fixed effects	Yes			Yes			Yes		
Federal state fixed effects	Yes			Yes			Yes		
Firm controls	Yes			Yes			Yes		
Log likelihood	-14526.392			-14420.085			-14406.758		
Left-censored observations	804			1283			1103		
Uncensored observations	4466			3987			4167		
Observations	5270			5270			5270		

Notes: Standard errors clustered by firm are reported in parentheses. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

3.5.3 Inverse probability weighting

Banks differ with respect to their business strategies, including risk characteristics, and this may imply specific matches with their corporate customers. Some banks may be prepared to bear risks connected with the financing of innovation projects as well as innovative firms in general, while others may not. If this conjecture were true, we have a selectivity problem, as the risk structure of banks is not independent of the risk structure of their corporate customers.

If the selectivity hypothesis is true, we observe two firm types. One type chooses banks with openness to risk and the other type of firm is associated with banks that are less prepared to finance risky projects. The aim is to eliminate any observable differences between the two firm types. For this purpose, we use inverse probability weighting to tackle selectivity on observables on the part of the firms as suggested by Imbens & Wooldridge (2009). Thus, we use the following two-step procedure: First, we estimate the probability of being related to a bank with high interbank market reliance. Second, we calculate the inverse of the obtained propensity score to weight the regressions of interest.

To determine the propensity score with a Probit model, we need to apply a dichotomous indicator to distinguish between control and treatment observations. We utilize the same approach as in Section 3.3.1 such that firms belong to the treatment group if they are related to a bank that has an interbank market borrowing-to-asset ratio in the top decile of the distribution. As control variables, we apply the firm-related variables used in the previous regressions. Moreover, as a measure for risky activities we use 'Industry innovation expenditures per employee'[19] which is the pre-crisis mean value of the logarithm of innovation expenditures per employee aggregated at the 2-digit NACE Rev. 2 industry level.

In Table 3.21 of Appendix 3.8.6, we present results of the Probit regression to compute the propensity score for each year. We calculate the inverse probability weight based on the obtained propensity score and apply it to each firm for the specific year. The tests on mean differences between the explanatory variables for our two samples using inverse probability weights are also presented in Table 3.22 of Appendix 3.8.6. It turns out that the means of the variables no longer differ between the control and treatment sample. Hence, the matching procedure is successful in eliminating differences in observables. Accordingly, we re-estimate our results using inverse probability weights as proposed by Imbens & Wooldridge (2009). Results of re-weighted regressions are given in Table 3.6.[20] Again, the interaction of interest is negative and highly significant at least at the 1 percent level for

[19] Results are similar when using research and development expenses per employee or sales with products newly introduced to the market. However, these indicators reduce the number of observations.

[20] Missing pre-crisis industry level innovation expenditure information causes a small sample reduction. Moreover, sample size decreases due to the fact that we restrict our sample to observations in the region of common support.

total innovation expenditures, investments in innovation projects and current innovation costs. These results are similar to the earlier results presented in Table 3.3 and coincide with the overall results of the earlier Tobit regressions.

Table 3.6: Determinants of innovation expenditures based on inverse probability weighting

Dependent variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Log of Total innovation expenditures			Log of Investments in innovation projects			Log of Current innovation expenditures		
	Tobit	Intensive	Extensive	Tobit	Intensive	Extensive	Tobit	Intensive	Extensive
Interbank	1.567	1.342	0.020	0.185	0.130	0.005	2.251*	1.727*	0.045*
	(1.150)	(0.986)	(0.015)	(1.320)	(0.930)	(0.034)	(1.298)	(0.995)	(0.026)
Interbank × Crisis	−3.882***	−3.327***	−0.049***	−4.449***	−3.136***	−0.116***	−4.493***	−3.448***	−0.090***
	(1.317)	(1.125)	(0.017)	(1.558)	(1.093)	(0.041)	(1.519)	(1.158)	(0.031)
Constant	6.599***			4.959***			2.949**		
	(1.201)			(1.752)			(1.328)		
Industry fixed effects	Yes			Yes			Yes		
Year fixed effects	Yes			Yes			Yes		
Federal state fixed effects	Yes			Yes			Yes		
Firm controls	Yes			Yes			Yes		
Log likelihood	-38576.705			-37819.622			-38133.583		
Left-censored observations	1077			1724			1486		
Uncensored observations	5845			5198			5436		
Observations	6922			6922			6922		

Notes: Standard errors clustered by firm are reported in parentheses. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

3.6 Test for the effects on other expenditures

Next, we test whether other expenditures were reduced in a similar way. For this purpose we estimate a similar specification for R&D and for marketing expenditures[21] separately. The results are presented in Table 3.7. We find a reduction of R&D expenditures, but a smaller and only weakly significant[22] effect on marketing expenses. The effect goes into the same direction as the findings of Campello et al. (2010) who find a strong, negative effect for marketing expenditures of firms which report being affected by the crisis. Nevertheless, compared to i.e. Campello et al. (2010) our treatment variable comprises the detailed situation of the individual banks of the firms.

Similarly to R&D, marketing activities do not offer collateral. Nevertheless, these expenditures are apparently regarded as being indispensable during a crisis and are not particularly risky, while R&D is definitely risky and can be delayed. Perhaps the firms regard marketing as particularly valuable if sales risks are substantial. Moreover, it might be the case that marketing expenditures are more sensitive to changes in internal financing. Accordingly, bank financing might not play a major role for marketing. The impact of constraints of the main bank on R&D expenditures is of a similar magnitude to the one reported with respect to total innovation expenditures and the two parts of that variable.

[21] Data for marketing expenditures is available from 2006.

[22] The effect for marketing expenditures turns out to be insignificant if we add e.g. bank variables to our regression. The estimates with R&D expenses as outcome variable are rather robust to these changes.

Table 3.7: Test for R&D expenditures and marketing expenses

Dependent variable	(1)	(2)	(3)	(4)	(5)	(6)
	Log of R&D expenditures			Log of Marketing expenditures		
	Tobit	Intensive	Extensive	Tobit	Intensive	Extensive
Interbank	1.442	1.046	0.033	1.453	1.414	0.004
	(1.270)	(0.922)	(0.029)	(0.986)	(0.959)	(0.003)
Interbank × Crisis	−3.015**	−2.188**	−0.069**	−1.733*	−1.686*	−0.005*
	(1.452)	(1.051)	(0.033)	(0.958)	(0.932)	(0.003)
Log of Employees	1.208***	0.877***	0.027***	0.959***	0.933***	0.003***
	(0.092)	(0.067)	(0.002)	(0.059)	(0.056)	(0.001)
Log of Firm age	−0.721***	−0.523***	−0.016***	−0.029	−0.028	0.000
	(0.151)	(0.109)	(0.004)	(0.084)	(0.082)	(0.000)
Part of firm group	0.029	0.021	0.001	0.252*	0.245*	0.001*
	(0.262)	(0.190)	(0.006)	(0.140)	(0.136)	(0.000)
Firm rating	−0.006**	−0.004**	0.000**	−0.005***	−0.005***	0.000***
	(0.003)	(0.002)	(0.000)	(0.002)	(0.002)	(0.000)
Sales growth	0.401	0.291	0.009	0.493**	0.480**	0.001**
	(0.359)	(0.261)	(0.008)	(0.218)	(0.212)	(0.001)
Export share	3.748***	2.720***	0.085***	1.297***	1.263***	0.004***
	(0.430)	(0.306)	(0.011)	(0.269)	(0.261)	(0.001)
Constant	3.425**			6.564***		
	(1.587)			(0.830)		
Industry fixed effects	Yes			Yes		
Year fixed effects	Yes			Yes		
Federal state fixed effects	Yes			Yes		
Log likelihood	-16998.855			-11038.388		
Left-censored observations	1535			328		
Uncensored observations	4717			4022		
Observations	6252			4350		

Notes: Standard errors clustered by firm are reported in parentheses. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

3.7 Conclusion

We provide evidence of the impact of a crisis-induced negative bank shock due to stress on the interbank market on the innovation activity of firms. For this purpose, we use data on firms provided by the Mannheim Innovation Panel concerning information on innovation activity. We are able to identify the main bank of each firm and exploit this information by combining the firm-level data with bank-specific balance sheet data from the Bankscope data set.

The recent financial crisis was characterized by distress on the interbank market. Our identification strategy relies on the fact that banks use this kind of funding to varying extents. The breakdown of the interbank market offers the opportunity to identify a cross-sectional dimension and differences between banks in refinancing themselves, as empirical studies provide evidence that banks relying heavily on this type of funding reduced the credit supply to corporate customers more sharply (Iyer et al. 2014; Cingano et al. 2016). Then the causal relation between the credit crunch due to the activities of the banks can be separated from individual firm effects.

Total innovation expenditures are analyzed within a difference-in-differences framework. The general result is that the banks' capacities for refinancing have an impact on the financing of their corporate customers' innovation expenditures. The decomposition of total innovation expenditures shows that investments in innovation are affected to a greater extent than current innovation costs, which probably comprise intangible expense. Hence, according to these results, external finance has an impact on innovative activity. Additional tests using R&D expenditures as outcome variable lead to similar results. Analyzing marketing expenditures, the results imply that there is a weakly significant impact on this kind of expenditure. This might indicate a lower sensitivity of marketing expenditures to external financing.

The financial crisis offers an interesting opportunity to investigate the effect of a drastic shock to the banks that was transmitted to firms in the form of reduced external financing. Summarizing, according to our empirical results both internal and external financing resources affect innovative activity, and an unfortunate event like the financial crisis not only has a short-run effect on current profits, but exerts a negative impact on the growth of the economy by affecting innovative activity. The study suggests that despite the well-known problems associated with it, external finance has a major effect on innovation activities. It may be that the banks trust in the long-run profitability of innovation activities, and this could be regarded as good news. An alternative explanation might be that the firms simply shift internal resources to the innovation departments if external sources are available to fund other projects. The arguably general aspect of our results beyond the analysis of the financial crisis is that innovation activities are sensitive to bank financing.

3.8 Appendix

3.8.1 Descriptive statistics

Figure 3.2: Distribution of the interbank borrowing to asset ratio for the 686 banks

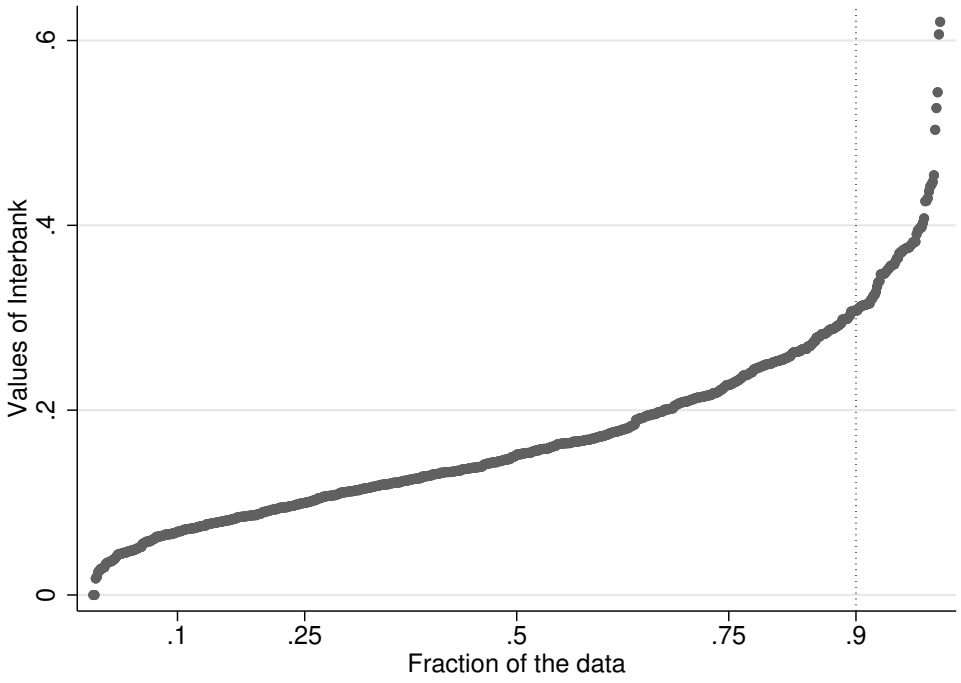


Figure 3.3: Kernel density estimates of the interbank borrowing to asset ratio for the 686 banks

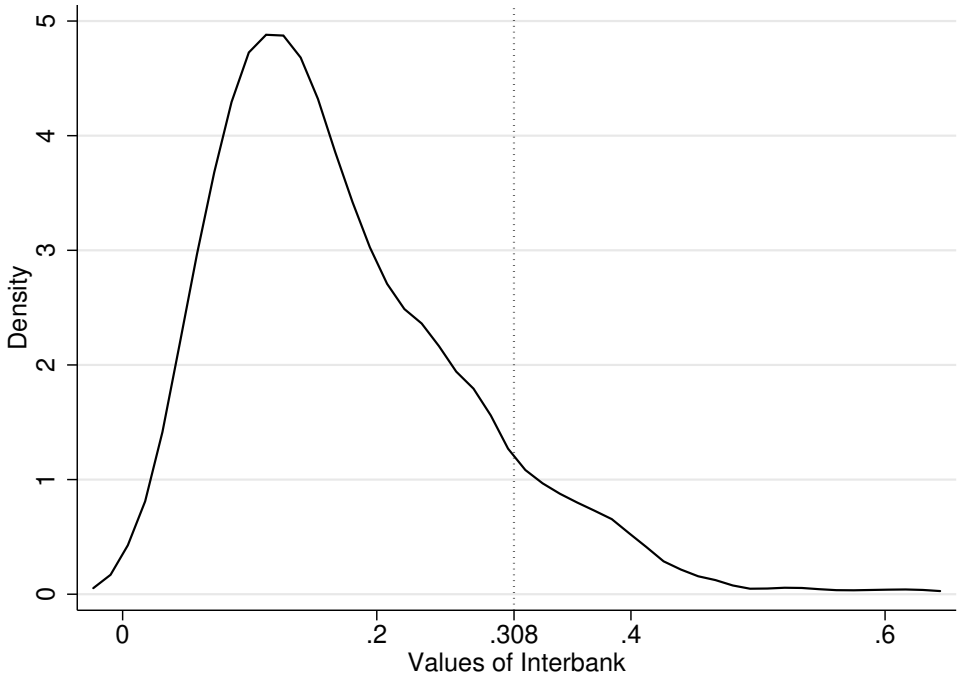


Table 3.8: Distribution of observations over industries

Name	NACE Rev. 2.0 code	Firms	Percentage share
Mining	5-9, 19, 35	94	2.691
Food/Tobacco	10-12	123	3.521
Textiles	13-15	144	4.123
Wood/Paper	16-17	106	3.035
Chemicals	20-21	230	6.585
Plastics	22	155	4.437
Glass/Ceramics	23	109	3.121
Metals	24-25	294	8.417
Electrical equipment	26-27	509	14.572
Machinery	28	366	10.478
Retail/Automobile	29-30	134	3.836
Furniture /Toys/Medical technology/Maintenance	31-33	238	6.814
Energy / Water	36-39	78	2.233
Media services	18, 58-60	126	3.607
IT/Telecommunications	61-63	288	8.245
Technical services/R&D services	71-72	383	10.965
Consulting/Advertising	69, 70.2, 73	116	3.321
Total		3493	100

Table 3.9: Distribution of firms over federal states

Name	Firms	Percentage share
Baden-Wuerttemberg	542	15.517
Bavaria	491	14.057
Berlin	109	3.121
Brandenburg	128	3.664
Bremen	49	1.403
Hamburg	58	1.660
Hesse	231	6.613
Lower Saxony	241	6.900
Mecklenburg-Vorpommern	58	1.660
North Rhine-Westphalia	587	16.805
Rhineland-Palatinate	105	3.006
Saarland	36	1.031
Saxony	391	11.194
Saxony-Anhalt	153	4.380
Schleswig-Holstein	77	2.204
Thuringia	237	6.785
Total	3493	100

Table 3.10: Count of observations per firm

Count of observations	Firms	Percentage share
1	1768	50.616
2	780	22.330
3	461	13.198
4	260	7.443
5	150	4.294
6	74	2.119
Total	3493	100

Table 3.11: Mean comparison for treatment and control group

	Mean		Difference in mean	p-value
	Control	Treatment		
Log of Total innovation expenditures	10.697	11.854	1.158***	0.000
Log of Investments in innovation projects	8.798	9.469	0.671***	0.000
Log of Current innovation expenditures	9.415	10.894	1.479***	0.000
Log of Employees	3.692	4.401	0.709***	0.000
Log of Firm age	2.987	3.006	0.019	0.357
Part of firm group	0.367	0.574	0.207***	0.000
Firm rating	226.380	215.442	−10.937 ***	0.000
Sales growth	0.054	0.061	0.007	0.202
Export share	0.193	0.274	0.082***	0.000

The treatment group consists of firms which are related to a bank in the upper 10% of the interbank distribution. Firms in the control group are associated with a bank in the lower 90% of the interbank distribution.

3.8.2 Results for the discretization of the treatment measure

Table 3.12: Difference in outcome variables for treatment and control Group – Treated: upper 25% of Interbank measure, control: lower 75%

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Mean				Difference		
	Pre-Crisis		Crisis				
	Control	Treatment	Control	Treatment	(3)-(1)	(4)-(2)	(6)-(5)
Panel A: Continuous outcome variables							
Log of Total innovation expenditures	10.617	11.893	10.746	11.380	0.129	−0.513***	−0.641**
					(0.534)	(0.001)	(0.014)
Log of Investments in innovation projects	8.985	9.819	8.607	8.910	−0.378*	−0.909***	−0.532*
					(0.085)	(0.000)	(0.057)
Log of Current innovation expenditures	9.496	10.941	9.367	10.272	−0.129	−0.669***	−0.540*
					(0.567)	(0.000)	(0.056)
Panel B: Binary outcome variables							
Non-Zero Total innovation expenditures	0.818	0.866	0.842	0.839	0.024	−0.027**	−0.050***
					(0.119)	(0.012)	(0.006)
Non-Zero Investments in innovation projects	0.759	0.788	0.736	0.723	−0.023	−0.064***	−0.041*
					(0.190)	(0.000)	(0.060)
Non-Zero Current innovation expenditures	0.759	0.823	0.760	0.780	0.000	−0.043***	−0.043**
					(0.989)	(0.000)	(0.037)

Notes: The treatment group consists of firms which are related to a bank in the upper 25% of the interbank distribution. Firms in the control group are associated with a bank in the lower 75% of the interbank distribution. For the differences in columns (5) - (7) p-values are given in parentheses. Column (7) shows difference-in-differences results. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

Table 3.13: Mean comparison for treatment and control group – Treated: upper 25% of Interbank measure, control: lower 75%

	Mean		Difference in mean	p-value
	Control	Treatment		
Log of Total innovation expenditures	10.689	11.627	0.938***	0.000
Log of Investments in innovation projects	8.774	9.347	0.574***	0.000
Log of Current innovation expenditures	9.424	10.594	1.170***	0.000
Log of Employees	3.658	4.278	0.619***	0.000
Log of Firm age	2.965	3.014	0.049**	0.022
Part of firm group	0.352	0.541	0.189***	0.000
Firm rating	227.844	216.842	−11.003 ***	0.000
Sales growth	0.051	0.061	0.010*	0.096
Export share	0.191	0.259	0.068***	0.000

The treatment group consists of firms which are related to a bank in the upper 25% of the interbank distribution. Firms in the control group are associated with a bank in the lower 75% of the interbank distribution.

Table 3.14: Difference in outcome variables for treatment and control group – Estimates including control variables

Dependent variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Log of Total innovation expenditures			Log of Investments in innovation projects			Log of Current innovation expenditures		
	Tobit	Intensive	Extensive	Tobit	Intensive	Extensive	Tobit	Intensive	Extensive
Treatment: Upper decile									
Interbank	0.303	0.260	0.004	−0.062	−0.044	−0.002	0.469*	0.360*	0.009*
	(0.221)	(0.189)	(0.003)	(0.278)	(0.196)	(0.007)	(0.251)	(0.193)	(0.005)
Interbank × Crisis	−0.623**	−0.533**	−0.008**	−0.653**	−0.461**	−0.017**	−0.682**	−0.523**	−0.014**
	(0.246)	(0.210)	(0.003)	(0.325)	(0.229)	(0.009)	(0.293)	(0.224)	(0.006)
Constant	7.018***			5.618***			3.108**		
	(1.141)			(1.511)			(1.338)		
Treatment: Upper quartile									
Interbank	0.388	0.332	0.005	0.027	0.019	0.001	0.460*	0.353*	0.009*
	(0.239)	(0.205)	(0.003)	(0.283)	(0.199)	(0.007)	(0.274)	(0.210)	(0.005)
Interbank × Crisis	−0.770***	−0.659***	−0.010***	−0.749**	−0.528**	−0.020**	−0.787**	−0.603**	−0.016**
	(0.267)	(0.228)	(0.004)	(0.336)	(0.236)	(0.009)	(0.321)	(0.246)	(0.006)
Constant	6.906***			5.588***			3.013**		
	(1.151)			(1.522)			(1.347)		
Industry fixed effects	Yes			Yes			Yes		
Year fixed effects	Yes			Yes			Yes		
Federal state fixed effects	Yes			Yes			Yes		
Firm controls	Yes			Yes			Yes		
Observations	6945			6945			6945		

Notes: Standard errors clustered by firm are reported in parentheses. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

3.8.3 Sensitivity to modeling choices

Table 3.15: Change in heteroscedasticity-term

Dependent variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Log of Total innovation expenditures			Log of Investments in innovation projects			Log of Current innovation expenditures		
	Tobit	Intensive	Extensive	Tobit	Intensive	Extensive	Tobit	Intensive	Extensive
Panel A: Baseline – Three size dummies, two age dummies and industry fixed effects									
Interbank	1.656*	1.418*	0.021*	0.273	0.193	0.007	2.236**	1.715**	0.045*
	(0.987)	(0.845)	(0.013)	(1.177)	(0.830)	(0.031)	(1.136)	(0.871)	(0.023)
Interbank × Crisis	−3.499***	−2.995***	−0.044***	−4.009***	−2.827***	−0.104***	−3.756***	−2.881***	−0.075***
	(1.101)	(0.940)	(0.015)	(1.408)	(0.991)	(0.037)	(1.325)	(1.013)	(0.027)
Constant	6.744***			5.526***			2.756**		
	(1.162)			(1.534)			(1.363)		
Panel B: Baseline variables, Group membership, Firm rating, Sales growth, Export share									
Interbank	1.744*	1.488*	0.022*	0.241	0.170	0.006	2.304**	1.767**	0.045**
	(0.995)	(0.850)	(0.013)	(1.170)	(0.826)	(0.030)	(1.141)	(0.874)	(0.023)
Interbank × Crisis	−3.514***	−3.000***	−0.045***	−4.010***	−2.830***	−0.103***	−3.787***	−2.903***	−0.075***
	(1.102)	(0.939)	(0.015)	(1.399)	(0.985)	(0.037)	(1.321)	(1.010)	(0.027)
Constant	6.554***			5.763***			2.672**		
	(1.095)			(1.518)			(1.318)		

(*continued*)

Table 3.15: *Continued*

Dependent variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Log of Total innovation expenditures			Log of Investments in innovation projects			Log of Current innovation expenditures		
	Tobit	Intensive	Extensive	Tobit	Intensive	Extensive	Tobit	Intensive	Extensive
Panel C: Log Employees, Log of Firm age and industry fixed effects									
Interbank	1.690*	1.445*	0.022*	0.118	0.083	0.003	2.335**	1.788**	0.046**
	(0.996)	(0.852)	(0.013)	(1.180)	(0.831)	(0.031)	(1.142)	(0.874)	(0.023)
Interbank × Crisis	−3.558***	−3.042***	−0.046***	−3.731***	−2.628***	−0.098***	−3.806***	−2.915***	−0.076***
	(1.113)	(0.949)	(0.015)	(1.416)	(0.995)	(0.037)	(1.324)	(1.011)	(0.027)
Constant	6.586***			5.418***			2.629**		
	(1.158)			(1.551)			(1.316)		
Panel D: All explanatory firm variables and industry fixed effects									
Interbank	1.731*	1.477*	0.022*	0.073	0.052	0.002	2.385**	1.826**	0.047**
	(1.005)	(0.858)	(0.013)	(1.175)	(0.828)	(0.030)	(1.150)	(0.880)	(0.023)
Interbank × Crisis	−3.528***	−3.009***	−0.045***	−3.692***	−2.603***	−0.096***	−3.839***	−2.940***	−0.076***
	(1.108)	(0.943)	(0.015)	(1.407)	(0.990)	(0.037)	(1.322)	(1.009)	(0.027)
Constant	6.516***			5.720***			2.610**		
	(1.119)			(1.546)			(1.293)		
Industry fixed effects	Yes			Yes			Yes		
Year fixed effects	Yes			Yes			Yes		
Federal state fixed effects	Yes			Yes			Yes		
Firm controls	Yes			Yes			Yes		
Observations	6945			6945			6945		

Notes: Standard errors clustered by firm are reported in parentheses. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

Table 3.16: Change in econometric model

Dependent variable	(1) Log of Total innovation expenditures			(4) Log of Investments in innovation projects			(7) Log of Current innovation expenditures		
	Tobit	Intensive	Extensive	Tobit	Intensive	Extensive	Tobit	Intensive	Extensive
Panel A: Baseline – Heteroscedastic Tobit									
Interbank	1.656*	1.418*	0.021*	0.273	0.193	0.007	2.236**	1.715**	0.045*
	(0.987)	(0.845)	(0.013)	(1.177)	(0.830)	(0.031)	(1.136)	(0.871)	(0.023)
Interbank × Crisis	−3.499***	−2.995***	−0.044***	−4.009***	−2.827***	−0.104***	−3.756***	−2.881***	−0.075***
	(1.101)	(0.940)	(0.015)	(1.408)	(0.991)	(0.037)	(1.325)	(1.013)	(0.027)
Constant	6.744***			5.526***			2.756**		
	(1.162)			(1.534)			(1.363)		
Panel B: Tobit									
Interbank	1.873*	1.633*	0.023*	0.789	0.551	0.023	2.273*	1.749*	0.051*
	(1.069)	(0.932)	(0.013)	(1.246)	(0.870)	(0.036)	(1.184)	(0.911)	(0.027)
Interbank × Crisis	−4.101***	−3.576***	−0.051***	−4.713***	−3.291***	−0.134***	−3.939***	−3.031***	−0.088***
	(1.170)	(1.015)	(0.016)	(1.443)	(1.005)	(0.042)	(1.360)	(1.043)	(0.031)
Constant	6.763***			5.712***			3.211***		
	(1.146)			(1.356)			(1.209)		

(*continued*)

Table 3.16: *Continued*

Dependent variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Log of Total innovation expenditures			Log of Investments in innovation projects			Log of Current innovation expenditures		
	Tobit	Intensive	Extensive	Tobit	Intensive	Extensive	Tobit	Intensive	Extensive
Panel C: OLS									
Interbank	1.642*			0.673			1.880**		
	(0.909)			(0.954)			(0.941)		
Interbank × Crisis	−3.495***			−3.585***			−3.169***		
	(0.989)			(1.091)			(1.071)		
Constant	7.381***			6.806***			4.692***		
	(0.954)			(1.011)			(0.925)		
Panel D: OLS with bank fixed effects									
Interbank × Crisis	−3.220***			−3.076***			−2.739**		
	(1.055)			(1.179)			(1.140)		
Constant	8.686***			8.107***			5.735***		
	(1.023)			(1.120)			(1.040)		
Industry fixed effects	Yes			Yes			Yes		
Year fixed effects	Yes			Yes			Yes		
Federal state fixed effects	Yes			Yes			Yes		
Firm controls	Yes			Yes			Yes		
Observations	6945			6945			6945		

Notes: Standard errors clustered by firm are reported in parentheses. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

Table 3.17: Results for a fixed effects Poisson quasi-maximum likelihood estimator

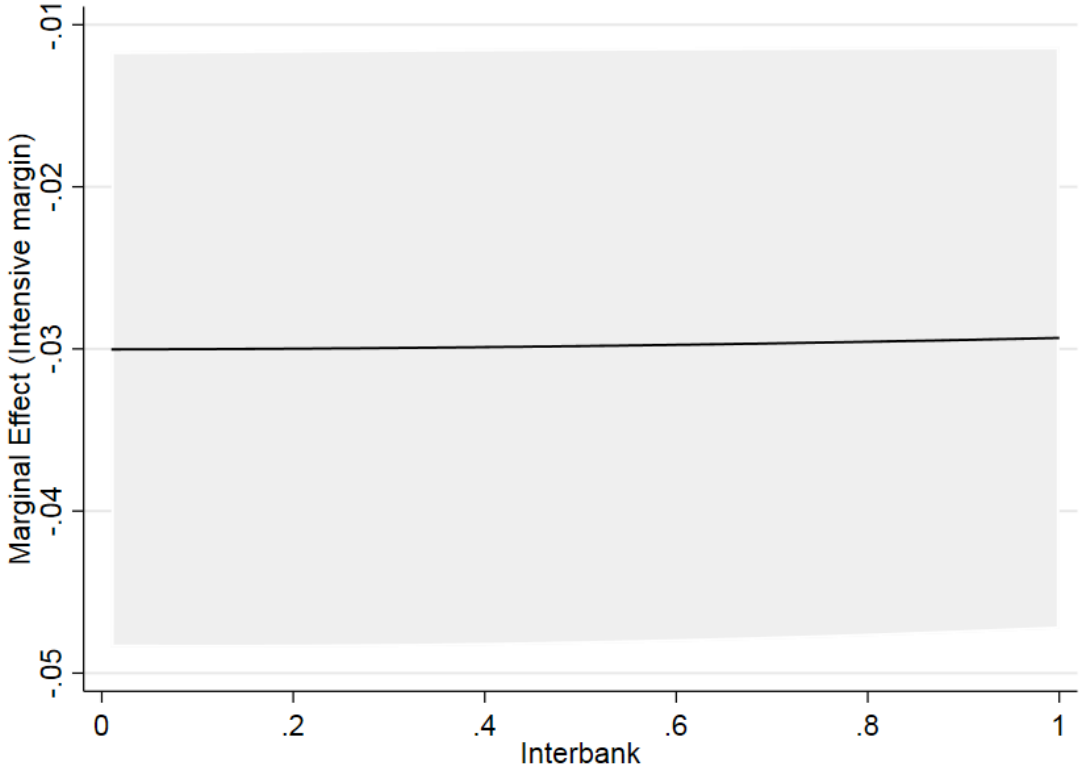
Dependent variable Dependent variable	(1) Log of Total innovation expenditures	(2) Log of Investments in innovation projects	(3) Log of Current innovation expenditures
Interbank	0.314	1.377	0.057
	(0.857)	(1.346)	(0.905)
Interbank × Crisis	−1.891**	−2.301**	−1.814*
	(0.887)	(1.123)	(0.940)
Industry fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
Federal state fixed effects	Yes	Yes	Yes
Firm controls	Yes	Yes	Yes
Observations	4885	4667	4760

Notes: Observation count is reduced to the restriction that each firm is observed at least twice in the sample period. Further restrictions in the observations stem from the requirement of the estimator that the outcome varies over the sample period. Robust standard errors are reported in parentheses. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

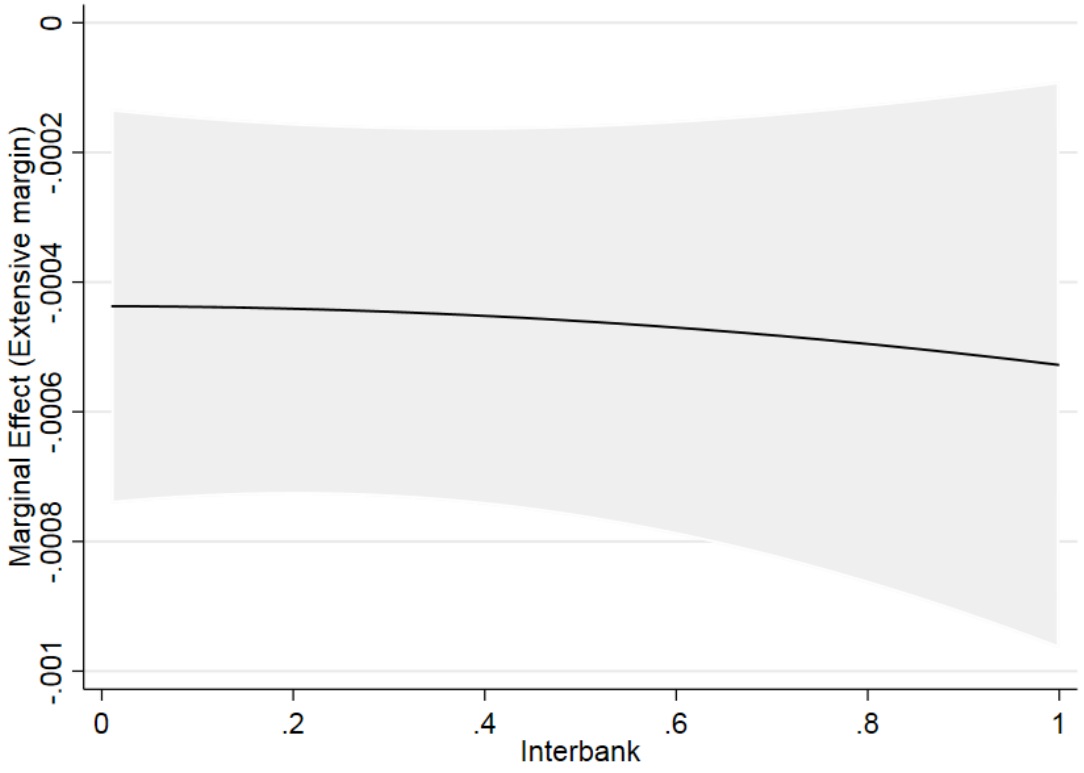
3.8.4 Effect heterogeneity and test on the common trend assumption

Treatment effect over the distribution of Interbank

Figure 3.4: The marginal effect on total investments in innovation expenditures over the distribution of the Interbank variable

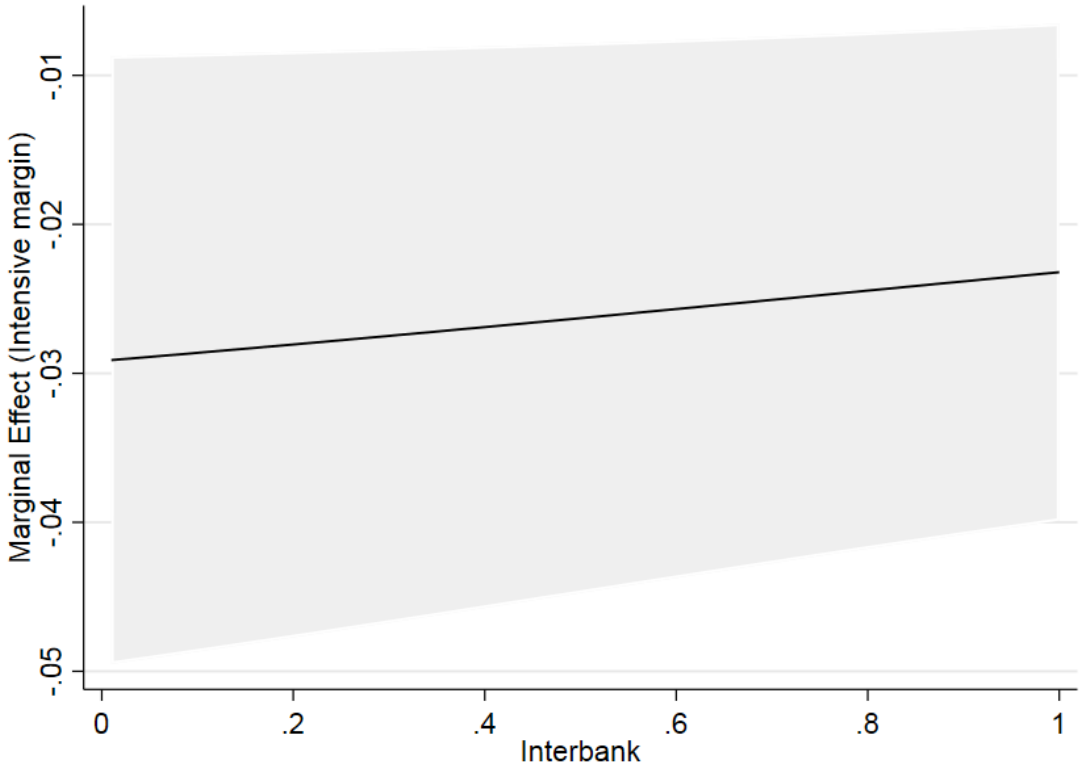


(a) Intensive margin

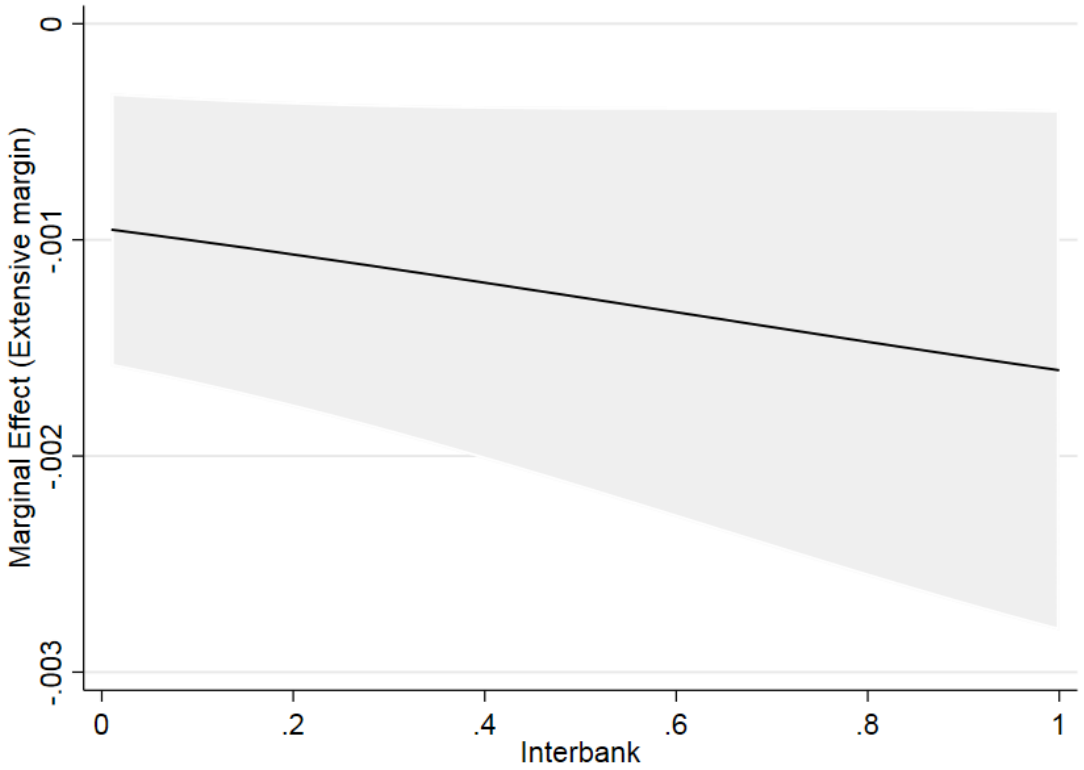


(b) Extensive margin

Figure 3.5: The marginal effect on investments in innovation projects over the distribution of the Interbank variable

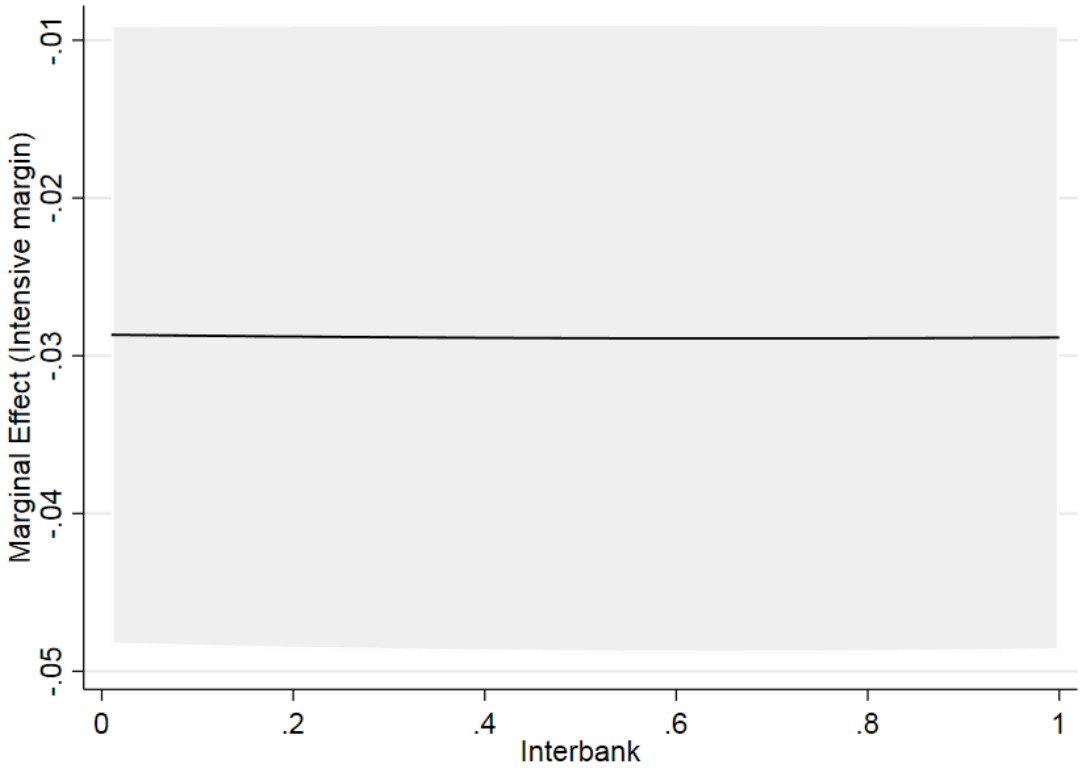


(a) Intensive margin

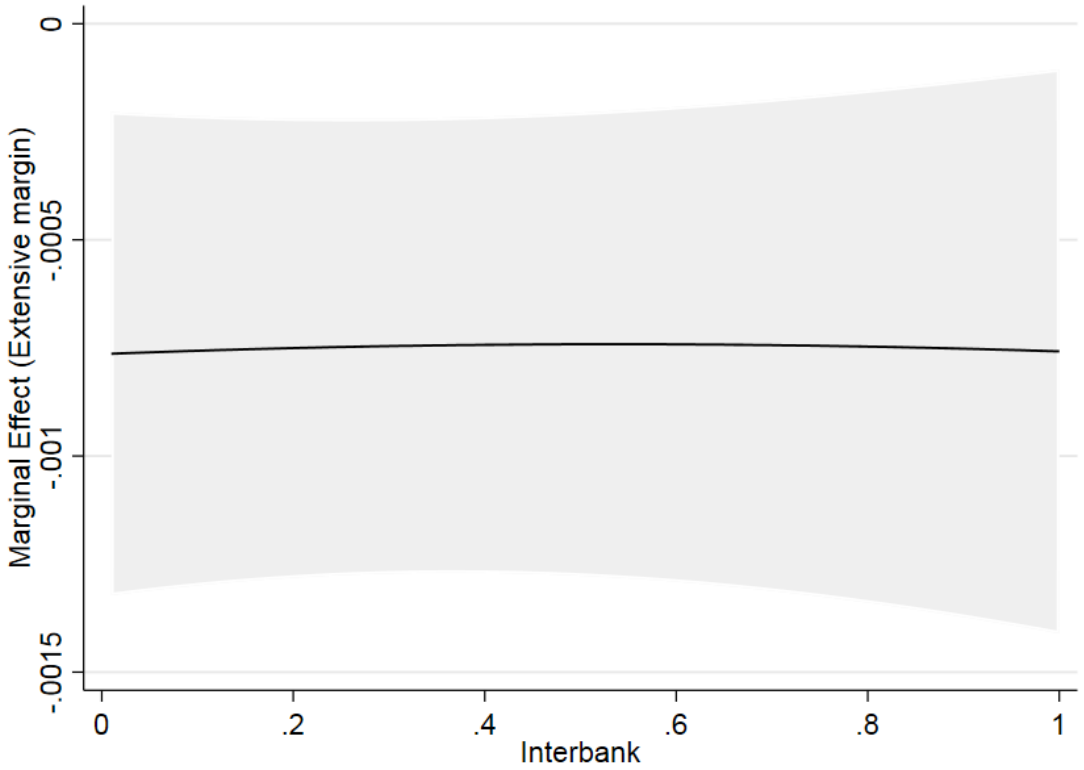


(b) Extensive margin

Figure 3.6: The marginal effect on current innovation expenditures over the distribution of the Interbank variable



(a) Intensive margin



(b) Extensive margin

Test on the common trend assumption

We test whether there was a significant difference in investment behavior prior to the first crisis year, 2008. In Table 3.18, we show the results of a more flexible version of the difference-in-differences estimator, proposed by Mora & Reggio (2015):

$$\ln(y_{it}) = \beta_0 + \beta_1 \text{Interbank}_{ij} + \sum_{\tau=2006}^{2010} \tau_t \text{Interbank}_{ij} \times \text{Year}_t + \beta_m X_m + \rho_i + \eta_i + \pi_t + \varepsilon_{it} \tag{3.2}$$

Thus, we interact our treatment variable Interbank with the full set of year dummies 'Year' except for the dummy for 2005, which serves as our basis year. Following Mora & Reggio (2015), we evaluate the parallel trend assumption in each year and test our null on common pre-treatment trends H_0: $\tau_t = 0 \quad \forall \quad t \leq 2007$ simultaneously.[23] The parallel trend assumption would be met if we do not reject H_0 at the ten percent level. Results reveal that the coefficients of the pre-crisis interactions are not significantly different from each other. Thus, the common trends assumption is met for each outcome.

[23] See e.g. Hangoma et al. (2018) and Yamamura (2016) for other applications.

Table 3.18: Test for a common trend

Dependent variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Log of Total innovation expenditures			Log of Investments in innovation projects			Log of Current innovation expenditures		
	Tobit	Intensive	Extensive	Tobit	Intensive	Extensive	Tobit	Intensive	Extensive
Interbank	1.312	1.123	0.017	0.664	0.469	0.017	2.772	2.126	0.055
	(1.456)	(1.247)	(0.019)	(1.782)	(1.257)	(0.046)	(1.951)	(1.496)	(0.039)
Interbank × 2006	1.509	1.292	0.019	0.076	0.054	0.002	0.621	0.476	0.012
	(1.793)	(1.535)	(0.023)	(2.212)	(1.560)	(0.058)	(2.324)	(1.782)	(0.046)
Interbank × 2007	−0.567	−0.486	−0.007	−1.142	−0.806	−0.030	−2.092	−1.604	−0.042
	(1.788)	(1.531)	(0.023)	(2.154)	(1.519)	(0.056)	(2.233)	(1.712)	(0.045)
Interbank × 2008	−3.675**	−3.146**	−0.047*	−4.427**	−3.123**	−0.115**	−3.880	−2.976	−0.077
	(1.853)	(1.585)	(0.024)	(2.216)	(1.561)	(0.058)	(2.393)	(1.834)	(0.048)
Interbank × 2009	−3.765*	−3.223*	−0.048*	−6.291**	−4.437**	−0.164**	−5.139**	−3.941**	−0.102**
	(1.960)	(1.676)	(0.025)	(2.534)	(1.785)	(0.067)	(2.377)	(1.820)	(0.048)
Interbank × 2010	−2.279	−1.951	−0.029	−2.823	−1.991	−0.074	−3.899	−2.990	−0.078
	(1.751)	(1.498)	(0.022)	(2.343)	(1.652)	(0.061)	(2.412)	(1.848)	(0.048)
Constant	6.802***			5.373***			2.561*		
	(1.203)			(1.572)			(1.451)		
H_0: common pre-treatment trends									
$\chi^2_{(1)}$	1.588	1.589	1.570	0.477	0.477	0.477	2.193	2.196	2.171
p-value	0.452	0.452	0.456	0.788	0.788	0.788	0.334	0.334	0.338
Industry fixed effects	Yes			Yes			Yes		
Year fixed effects	Yes			Yes			Yes		
Federal state fixed effects	Yes			Yes			Yes		
Firm controls	Yes			Yes			Yes		
Log likelihood	-19347.717			-19019.001			-19140.466		
Left-censored observations	1077			1726			1486		
Uncensored observations	5868			5219			5459		
Observations	6945			6945			6945		

Notes: Standard errors clustered by firm are reported in parentheses. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

Table 3.19: Test for a heterogeneous treatment effect

Dependent variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Log of Total innovation expenditures			Log of Investments in innovation projects			Log of Current innovation expenditures		
	Tobit	Intensive	Extensive	Tobit	Intensive	Extensive	Tobit	Intensive	Extensive
Interbank	1.655*	1.417*	0.021*	0.275	0.194	0.007	2.235**	1.714**	0.044*
	(0.987)	(0.845)	(0.013)	(1.177)	(0.830)	(0.031)	(1.136)	(0.871)	(0.023)
Interbank × 2008	−4.014***	−3.436***	−0.051***	−4.037**	−2.847**	−0.105**	−3.337*	−2.559*	−0.066*
	(1.425)	(1.217)	(0.019)	(1.670)	(1.176)	(0.044)	(1.725)	(1.321)	(0.035)
Interbank × 2009	−4.104***	−3.513***	−0.052**	−5.901***	−4.162***	−0.154***	−4.599***	−3.528***	−0.092***
	(1.571)	(1.343)	(0.020)	(2.103)	(1.481)	(0.055)	(1.741)	(1.332)	(0.035)
Interbank × 2010	−2.619*	−2.242*	−0.033*	−2.432	−1.716	−0.063	−3.360*	−2.577*	−0.067*
	(1.342)	(1.147)	(0.017)	(1.865)	(1.315)	(0.049)	(1.787)	(1.369)	(0.036)
Constant	6.731***			5.491***			2.741**		
	(1.162)			(1.534)			(1.363)		
H_0: No difference in Interbank interaction terms									
	1.263	1.264	1.255	2.468	2.470	2.454	0.547	0.547	0.546
p-value	0.532	0.532	0.534	0.291	0.291	0.293	0.761	0.761	0.761
Industry fixed effects	Yes			Yes			Yes		
Year fixed effects	Yes			Yes			Yes		
Federal state fixed effects	Yes			Yes			Yes		
Firm controls	Yes			Yes			Yes		
Log likelihood	-19348.394			-19019.162			-19141.332		
Left-censored observations	1077			1726			1486		
Uncensored observations	5868			5219			5459		
Observations	6945			6945			6945		

Notes: Standard errors clustered by firm are reported in parentheses. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

3.8.5 Descriptive statistics for bank switching

Table 3.20: Switching firms and the direction of switching

Year	(1) Switching the main bank from year t to t-1		(3) Interbank value available in year t and t-1		(5) Larger Interbank Value in year t compared to t-1	
	Absolute	Share	Absolute	Share	Absolute	Share
2005	155	4.440	105	67.741	48	45.710
2006	136	3.890	104	76.471	54	51.920
2007	122	3.490	110	90.164	51	46.360
2008	99	2.830	88	88.889	39	44.320
2009	112	3.210	102	91.071	43	42.160
2010	103	2.950	94	91.262	43	45.740

Notes: Reference for the share value in Column (2) is the overall number of firms (3493) as we observe the bank account history for all firms in our sample over time. For the share in Column (4), the reference is the absolute number of bank switching firms in Column (1). The value in Column (6) has its reference in the absolute quantity of available interbank information in Column (3).

3.8.6 Matching procedure

Table 3.21: Matching results to obtain the propensity score for the construction of the inverse probability weights

Dependent variable	Treated
Log of Employees	0.168***
	(0.014)
Log of Firm age	−0.029
	(0.022)
Part of firm group	0.339***
	(0.036)
Firm rating	−0.001***
	(0.000)
Sales growth	0.071
	(0.071)
Export share	0.527***
	(0.071)
Industry innovation expenditures per employee	0.097***
	(0.031)
Constant	−1.472***
	(0.383)
Industry fixed effects	Yes
Year fixed effects	Yes
Federal state fixed effects	Yes
Ps. R-Square	0.105
Log likelihood	-4299.316
Observations	6941

Notes: Standard errors in parentheses. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

Table 3.22: Mean comparison after matching – Means Calculated Using Inverse Probability Weights

	Mean		Difference in mean	p-value	Normalized difference
	Control	Treatment			
Log of Employees	4.031	4.040	0.010	0.714	0.004
Log of Firm age	2.986	2.995	0.010	0.506	0.008
Part of firm group	0.469	0.471	0.002	0.784	0.003
Firm rating	220.280	220.090	−0.190	0.810	−0.003
Sales growth	0.059	0.059	0.000	0.984	0.000
Export share	0.230	0.234	0.004	0.365	0.011
Industry innovation expenditures per employee	9.669	9.673	0.004	0.756	0.004

The treatment group consists of firms which are related to a bank in the upper 10% of the interbank distribution. Firms in the control group are associated with a bank in the lower 90% of the interbank distribution. Normalized differences are reported as suggested by Imbens & Wooldridge (2009). Values smaller than 0.25 indicate a satisfying balance of covariates.

Chapter 4

Bank credit supply and firm innovation behavior in the financial crisis

Co-authored with Kornelius Kraft

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4.1 Introduction

The financial crisis of 2008/2009 marks a period of turbulences in the banking sector that were followed by adverse effects on the real economy. In Germany, these effects were manifested for example as a decrease in GDP (-5%), exports (-14.2%) and fixed investments (-8.8%) in 2009 compared to 2008 (OECD 2010). Aside of these general economic indicators, OECD (2012) also shows that for Germany long-term investments like R&D expenditures from business enterprises shrink by 3% and patent filing by about 11.5% from 2008 to 2009. Similar figures are observed for many other OECD countries including Canada, the UK and the US. Aside of these descriptive observations, it is empirically established that in response to the reduction in bank credit supply (e.g. Ivashina & Scharfstein 2010; Iyer et al. 2014; Liberti & Sturgess 2018), firms have reduced, among others things, their labor demand (e.g. Chodorow-Reich 2014), investment (e.g. Cingano et al. 2016; Dwenger et al. 2018; Vermoesen et al. 2013) or trade activities (Chor & Manova 2012). However, detailed empirical evidence concerning the impact of bank credit supply restrictions as determinant of firm innovation behavior during the financial crisis is scarce.[1]

Studying the relation between bank credit supply and innovation in the recent financial crisis is of particular interest for several reasons: A negative shock to bank credit supply which has adverse effects on innovation consequently affects growth, development and competitiveness negatively.[2] Moreover, the financing of innovation differs from – and is more difficult than – the financing of normal assets, which is rooted in the special characteristics of innovation projects (i.e. a long duration, huge uncertainties and other risks) (e.g. Hall 2002; Hall & Lerner 2010; He & Tian 2018; Kerr & Nanda 2015). Additionally, the existence of a relation between bank financing and innovation remains under discussion (Hall & Lerner 2010; Kerr & Nanda 2015). Consequently, the aim of this paper is to investigate the effect of individual main bank changes in credit supply during the recent financial crisis on their corporate customers' immediate innovation adjustments and innovation strategy. In that respect we determine the impact of bank credit supply changes on (i) ongoing, current innovation activities, (ii) the initiation of additional innovation and (iii) the reallocation of unused labor to the innovation department. Moreover, we investigate whether the crisis-induced variation in bank credit supply leads to (iv) more emphasis on innovation-related strategies in reaction to the crisis.

Our data basis is the 2010 wave of the Mannheim Innovation Panel (MIP), which is the German section of the Community Innovation Survey (CIS). The MIP provides general information on firms, including basic characteristics like size and turnover but also information regarding innovation activity. As we are interested in the changes in innovation behavior during the financial crisis in direct relation to the credit supply of firms' banks,

[1] We discuss similarities and differences to existing work in detail at the end of this section.

[2] See for example works like Aghion et al. (2005), Romer (1986); Romer (1990); Solow 1957 which show that innovations are important drivers for economic growth, development and competitiveness.

we make use of the 2010 wave of the MIP. There are several advantages to using this data source. Firstly, this wave contains a particular section in which firms were asked about their immediate changes in innovation activities due to the financial crisis. These survey-based measures allow for a detailed picture of the changes in innovation activity during the financial crisis related to the credit supply of banks.[3] Thus, we can determine the impact on current innovation activities as well as the initiation of new, additional innovation. Moreover, we can distinguish the latter in product and process innovation. Secondly, an advantage of the MIP is that we are able to identify the firm's main bank. This allows us to combine the firm information and survey-based measures on immediate firm decisions regarding the innovation activities with bank balance sheet information. The latter information on bank balance sheets is taken from Bankscope, compiled by Bureau van Dijk.

To exploit the rather under-investigated channel from bank lending constraints to firm innovation activity, we use the financial crisis 2008/2009 as a natural experiment. As we focus on Germany, a bank-based economy (e.g. Boot 2000), this shock to the bank system delivers a suitable opportunity to explain the relationship between bank financing and innovation.[4] Our identification strategy is based on the shock to the interbank market. We use the fact that high risk premia and uncertainties led to liquidity problems for banks relying heavily on the interbank market to obtain financial resources. Thus, we employ dependence on the interbank market as a major determinant of a bank's refinancing constraints (e.g. Cingano et al. 2016; Iyer et al. 2014). We apply this supply-side instrument to explain crisis-induced lending reductions by banks. This in turn allows us to estimate the causal effect of changes in bank credit supply on current and prospective corporate innovation activities during the financial crisis in an instrumental variable approach.

Using this direct measure for the effect of the crisis on a bank's refinancing capabilities, we identify the effect for lending capacities and then investigate how bank credit supply affected corporate innovation during the financial crisis. We show that these consequences of the crisis significantly explain the reduction in innovation activities among business customers due to (self-reported) increased difficulties in financing innovation. Accordingly, we find that firm innovation activities react sensitively to bank financing. In that respect, by identifying the mechanism of how innovation is reduced, we make an important step further than existing studies that investigate the relationship between the crisis and innovation (e.g. Archibugi et al. 2013a; Archibugi et al. 2013b; Campello et al. 2010; Filippetti & Archibugi 2011; Giebel & Kraft 2019; Huber 2018; Paunov 2012). Firstly, we show that current innovation activities are affected by the negative shock to bank financing. Thus, we find that a decrease in bank lending increases the probability of reducing innovation activities due to funding shortages. Moreover, our results contribute to the discussion on

[3] See He & Tian (2018) for a discussion of problems related to the use of R&D or patent measures when analyzing the relationship between finance and innovation.

[4] In the case of Germany, bank financing is the most prevalent source of financing.

the different effects of bank financing on product and process innovation (e.g. Alessandrini et al. 2010; Benfratello et al. 2008). Thus, secondly, we show that business customers with relations to a bank with higher credit growth are more likely to initiate additional innovation activities during the crisis. In that respect, higher loan growth leads to a higher probability of initiating additional product innovation. Moreover, we find a much weaker (positive) effect of higher loan growth on the probability of initiating additional process innovation. Thirdly, our results indicate that firms which have access to a bank with high loan growth are more likely to allocate unused resources like labor to the innovation department.[5] Several robustness tests (i.e. accounting for a possible endogenous matching of firms and banks, handling demand effects and refining the definition of the dependent variable) support the validity of our results.

Tests on the heterogeneity of our results reveal that the sensitivity of innovation to changes in credit supply is predominantly relevant for firms that are more likely to be internally constrained. Thus, firms that faced a sales contraction in the crisis adjusted their innovation in relation to the change in bank lending. Moreover, firms that react more sensitively to reductions in sales or profits during the crisis are also more sensitive to the bank credit supply shock. These results might point towards an additionality of bank financing rather than a complementarity to internal financing.

Lastly, we do not find a link between the change in credit supply and the impact of any innovation-related strategy in reaction to the crisis. Thus, we show that the firm's emphasis on cost-reducing strategies to react to the changing economic conditions of the crisis is independent of the change in bank credit supply. Moreover, the change in bank credit supply does not affect the firm's impact of an exploration or exploitation strategy to react to the crisis. Thus, the bank credit supply shock affects the immediate innovation behavior but not the innovation strategy in reaction to the crisis. This holds even if we estimate the impact on condition of being affected by the crisis (or not) or on conditional of an innovation adjustment in the short run (or not).

Our study contributes to several strands of literature. Firstly, we complement the literature that investigates determinants of firm innovation behavior during the financial crisis (e.g. Archibugi et al. 2013a; Archibugi et al. 2013b; Campello et al. 2010; Filippetti & Archibugi 2011; Hud & Hussinger 2015; Paunov 2012). These studies focus on several firm characteristics (i.e. size, past experiences with crises) but not explicitly on bank financing. Thus, we complement these by considering external financing in terms of bank lending in detail. Additionally, the studies mentioned above focus on firm changes in innovation expenditures (Archibugi et al. 2013a; Archibugi et al. 2013b; Campello et al. 2010; Filippetti & Archibugi 2011) or a dummy variable for abandoned innovation projects (Paunov 2012). The information derived from these measures does not reflect the detailed

[5] This research question is based on the assumption that to some degree resources can be shifted within the firm from one department to the other if they are not currently needed in their original department. For a more general view see Teece 1980.

changes in the innovation behavior of firms (e.g. He & Tian 2018). Thus, we extend this literature by focusing on immediate changes in firms' innovation activities and strategy due to changes in bank loan supply. In that respect we also contribute to the literature on the cyclicality of innovation (e.g. Aghion et al. 2012; Barlevy 2007; López-Garcia et al. 2013) as our results support the finding that credit constraints lead to pro-cyclical innovation behavior in economic downturns (e.g. Aghion et al. 2012) and that firms without credit constraints invest in innovation projects in a counter-cyclical manner.

Secondly, we contribute to existing studies which focus on the financing of innovation and bank financing in particular. Thus, we extend empirical studies which reveal that innovation activities are indeed sensitive to the characteristics of the firm-bank relationship (e.g. Cosci et al. 2016; Giannetti 2012; Herrera & Minetti 2007). Moreover, we contribute to empirical studies showing that county level bank de-regulation (e.g. Amore et al. 2013; Chava et al. 2013; Cornaggia et al. 2015), regional bank characteristics (e.g. Alessandrini et al. 2010; Benfratello et al. 2008; Hsu et al. 2014) or regional bank distress (e.g. Nanda & Nicholas 2014) and innovation behavior of firms are not independent of each other. Consequently, it is quite likely that bank credit supply affects firm innovation. We generally add to these strands of literature by investigating the effects during the financial crisis. Moreover, we extend these strands of literature by exploiting firm-bank data to directly investigate the detailed effects of changes in bank credit supply on corporate innovation. Moreover, utilizing firm-bank level data, we shed light on - and contribute to - the quite ambiguous findings of Benfratello et al. (2008) and Alessandrini et al. (2010) with respect to the sensitivity of product and process innovation to bank characteristics. Our finding of a strong reaction of product innovation to the change in bank credit supply and a weaker one for process innovation complement the findings of Alessandrini et al. (2010).

Thirdly, we complement the literature which investigates the effect of a credit supply shock in the recent financial crisis 2008/2009 on firm outcomes by using firm-bank data (e.g. Balduzzi et al. 2018; Bentolila et al. 2017; Chodorow-Reich 2014; Cingano et al. 2016; Dwenger et al. 2018; Giebel & Kraft 2019; Huber 2018; Iyer et al. 2014; Popov & Rocholl 2018). We generally enrich this literature by providing direct measures taken by firms with respect to innovation activity dependent on bank credit supply during the financial crisis. We complement the very recent analysis of Huber (2018), who tests for the effect of the bank credit supply shock of Commerzbank-related firms on, among others, productivity and employment. Huber (2018) also tests for the persistency of negative bank shock to Commerzbank-related firms by analyzing patenting. Firstly, our measure of the bank credit supply shock allows for a more detailed identification and interpretation of the effects of a negative bank shock. Secondly, we extent Huber's (2018) analysis by providing information on the immediate decisions of firms concerning their innovation activities based on the loan supply by banks. Our results might help to explain the finding in Huber (2018) that a patenting reduction between 2009 and 2012 is driven by the years 2011 onwards as a patent is the outcome of the innovation process in the firm. For a

similar reason we extend the work of Giebel & Kraft (2019) which shows that innovation expenditure decreases for firms affected by the negative shock to the interbank market. However, similar to Huber (2018), their innovation measure does not allow for a detailed determination of the underlying changes in innovation behavior and strategy.

The remainder of the paper is structured as follows. The second Section 4.2 covers a description of the channels affecting the innovation activity of firms during the financial crisis. The third Section 4.3 covers a description of the data and variables, as well as methodology. The results are described in Section 4.4. Section 4.5 comprises descriptions and results for robustness tests and extensions. The sixth and last section of Chapter 4 concludes.

4.2 Bank financing and innovation in the recent financial crisis

4.2.1 Bank financing and innovation

In the case of a perfect capital market it might be no problem to obtain the necessary amount of funding for investment projects of any type (Modigliani & Miller 1958). However, capital market imperfections and asymmetric information problems lead to restricted access to external funding (Holmstrom & Tirole 1997; Stiglitz & Weiss 1981). Accordingly, the nature of innovation projects leads to a large gap between internal and external costs of financing, resulting in an underinvestment in innovation (Hall 2002; Hall & Lerner 2010; Hottenrott & Peters 2012). Empirical studies show that significant problems for innovative firms attempting to access external capital exist (e.g. Cowling et al. 2018; Freel 2007; Lee & Brown 2016; Mina et al. 2013). The resulting financing constraints seriously hamper innovation activities (e.g. Ayyagari et al. 2011; Canepa & Stoneman 2005; Mohnen et al. 2008; Savignac 2008) or lead to an underinvestment in R&D (e.g. Czarnitzki & Hottenrott 2011a; Czarnitzki & Hottenrott 2011b).

Even if evidence for the relationship between financing constraints and innovation exists, it might be debatable whether bank financing and innovation behavior of firms are related (e.g. Hall & Lerner 2010; Kerr & Nanda 2015). The argument might be raised that the characteristics of innovation (e.g. low collateral, large uncertainties) make bank financing inappropriate for innovation (Hall & Lerner 2010). Contrary to this argument, the characteristics of innovation (i.e. large adjustment costs) make it more valuable for firms to source debt than to cut innovation (e.g. Knudsen & Lien 2014). Costly debt can be refinanced at a later date, whereas the rebuilding of an incapacitated R&D department is likely to be much costlier. As argued by Knudsen & Lien (2014), the difference in the reversibility between both options (cutting innovation vs. increasing debt) drives the pref-

erence for debt. Studies show that characteristics of the firm-bank relationship (e.g. Cosci et al. 2016: Giannetti 2012; Herrera & Minetti 2007) and regional bank characteristics (i.e. deregulation) impact firm innovation (e.g. Alessandrini et al. 2010; Amore et al. 2013; Benfratello et al. 2008; Chava et al. 2013; Cornaggia et al. 2015; Hsu et al. 2014; Nanda & Nicholas 2014).

4.2.2 Bank credit supply shock and firm innovation in the recent financial crisis

As most firms in bank-based economies like Germany depend to some degree on bank loans[6] (e.g. Agarwal & Elston 2001; Berger & Udell 1995; Boot 2000) a negative shock to bank lending like the recent financial crisis will affect their availability of financing. This is first rooted in the fact that, in all likelihood, a negative shock to banks will lead to a lower supply of bank credit in general (Chava & Purnanandam 2011; Kahle & Stulz 2013; Upper & Worms 2004). For Europe and Germany it is shown that the financial crisis of 2008/09 led to a credit supply reduction to the real sector (Bundesbank 2009; Cingano et al. 2016; Dwenger et al. 2018; Iyer et al. 2014; Meriläinen 2016; Puri et al. 2011). Secondly, a negative shock to banks leads to adverse effects on borrowing costs (Upper & Worms 2004). This is the consequence of the increased asymmetric information problem between borrower and lender (Mishkin 1992), lower valuation of collateral (Bernanke & Gertler 1989; Bernanke & Gertler 1990) and the increase in the perception of risk (Bloom 2007). This is also observed during the recent financial crisis for Europe and Germany (e.g. de Bondt et al. 2010; Gilchrist & Mojon 2018; Lee et al. 2015). Additionally, financing is hampered even if firms try to substitute away from bank funding to other sources such as equity, since these financing sources are also affected (Kahle & Stulz 2013).

As the recent financial crisis was also accompanied by a reduction in demand, it is questionable if and how firms adjust their innovation activity in a recession. On the one hand, it might be argued that the innovation behavior of firms is expected to be pro-cyclical in an economic downturn as the decrease in demand provides no incentive to invest in innovation (Schmookler 1966; Shleifer 1986). On the other hand, the investment in innovation in an economic downturn could be counter-cyclical due to the opportunity cost effect (e.g. Barlevy 2007; Knudsen & Lien 2014). This is rooted in the firm's desire for productivity-enhancing measures and the low opportunity costs for the reallocation of productive assets (like labor) from manufacturing to innovation (e.g. Aghion & Saint-Paul 1998; Davis & Haltiwanger 1990; Stiglitz 1994). Aside of the opportunity cost effect, financing constraints play a crucial role when determining the innovation behavior of firms in an economic downturn (e.g. Knudsen & Lien 2014). As argued by Aghion et al. (2010) and Aghion et al. (2012), in the case of a perfect capital market, firms might prefer to

[6]The bank lending channel in Germany is investigated by e.g. Worms (2003); Ehrmann & Worms (2004); Upper & Worms (2004).

invest counter-cyclically in long-term growth opportunities during a recession. However, as argued above, asymmetric information and other problems lead to imperfections on financial markets, resulting in financial constraints. Thus, innovation investments are found to be pro-cyclical when firms face external financing constraints in an economic downturn (Aghion et al. 2010; Aghion et al. 2012; López-Garcia et al. 2013).

Following these considerations, a reduction in actual innovation activities during the financial crisis due to a bank credit supply shock occurs for to several reasons: firstly, as a direct result if firms do not get the desired loans for their innovation projects; secondly, as an indirect result following the reallocation of capital within the firm (e.g. Lamont 1997; Shin & Stulz 1998; Stein 1997).[7] Thus, firms might shift their scarce financial resources to more essential projects (i.e. running current business) or more productive ones. Regarding the financing of innovation, it is quite likely that firms do not directly lend for - but use free borrowing capacities from physical assets to fund – innovation (Knudsen & Lien 2014). Thus, innovation might decline if there are no unused borrowing capacities for other investment types which could be allocated to innovation (e.g. Knudsen & Lien 2014). Moreover, innovation is affected negatively if existing unused borrowing capacities decline due to more restrictive bank lending and lower collateral value in a recession (Knudsen & Lien 2014). Consequently, firms facing a negative bank credit supply shock like the recent financial crisis are likely to reduce their innovation activities due to funding shortages if their bank reduces its credit supply.

Besides the impact of a shock to bank lending on ongoing innovation activities, it also affects the initiation of new innovation activities. In addition to the prevailing, more intense, asymmetric information problems during the financial crisis, there is also the fact that firms prefer to use predominantly internal means in early innovation stages (e.g. Carreira & Silva 2010; Fazzari et al. 1988). Thus, for the initiation of new, additional innovation activities, the argument might be raised that there is a limited impact of external financing (e.g. Garcia-Quevedo et al. 2018). However, taking the picture from the capital allocation site within the firm, an impact on the innovation initiation of firms could be expected. This might be rooted in the fact that the information asymmetry between the R&D division and the firm management might be enhanced in the case of new innovation activities (Seru 2014). Thus, in times of scarce financial means, capital might not be allocated to the innovation department for the initiation of additional innovation activities. Consequently, depending on the availability of bank financing for the firm, we expect that firms related to a bank with higher credit growth in the financial crisis are more likely to initiate additional innovation projects.

H1: Firms' immediate adjustment of innovation activities during the recent financial crisis depends on the credit supply of their main bank.

[7] Capital reallocation within firms led to a mitigation of financial frictions in the recent financial crisis (Matvos & Seru 2014).

Bank financing (and the problems of it) might affect the decisions to initiate new product and process innovation projects differently. Both types differ with respect to several characteristics e.g. goals, external financing requirements and subjectivity to asymmetric information. Reasons to conduct a process innovation include reaching the technological state of the art, reducing costs or increasing competitiveness (Alessandrini et al. 2010; Dosi 1988; Dachs et al. 2017). Product innovations on the other hand are primarily conducted to increase the firm's sales (market share) and competiveness (Alessandrini et al. 2010; Dosi 1988). In good times, the profit prospects of new product innovations are probably especially promising, in which case they might dominate process innovation. In contrast, during a recession or depression, cost reductions presumably have the highest priority, favoring process over product innovation.

Process innovation is usually implemented by new investment in equipment and machinery (e.g. Sirilli & Evangelista 1998) and this in turn is frequently realized by external financing (Berggren et al. 2000). Product innovation makes capital investments for commercialization and production necessary as well (Alessandrini et al. 2010). However, the asymmetric information problem for product innovation might be greater in earlier stages, as this type of innovation requires a lot of creativity and strategic thinking (Alessandrini et al. 2010). Accordingly, both types of innovation might be affected by financial constraints.[8] Nevertheless, because of the higher relevance of information problems and the relevance for long-run aims (higher profits in the future) but not short-run improvements, product innovation might be more sensitive to restrictions in financial conditions.

H2: The initiation of both additional product and process innovation is subject to the availability of bank financing in the financial crisis.

Besides capital (e.g. Lamont 1997; Shin & Stulz 1998; Stein 1997), labor is also reallocated within the firm (e.g. Giroud & Mueller 2015). Thus, under the assumption of existing innovation opportunities, unused human resources[9] might be shifted to the innovation department. One the one hand, such a reallocation is e.g. possible if production departments are overstaffed during a crisis and the human resources are temporarily of higher use in innovation departments (if their skills fit). This would especially take place if firms are facing declines in demand for specific products, such that human resources are allocated away from these. On the other hand, the shift of unused human resources to innovation might result from the termination of other innovation processes. Both options (reallocation from production and reallocation from terminated innovation projects) are taking place under the assumption that the firm has sufficient financial resources at its

[8] This is also evident in the empirical literature (e.g. Alessandrini et al. 2010; Benfratello et al. 2008). Investigating the impact of bank development on innovation, Benfratello et al. (2008) find a strong effect on process innovation as well as a weak and not robust effect on product innovation. Alessandrini et al. (2010) on the one hand find that, functionally, distance between the banking system and the local economy impacts both product and process innovation. Additionally, their results imply that the market share of large banks is only weakly correlated with the introduction of product innovation.

[9] Following Teece (1980), firms are able to shift inputs like capital and labor between production processes.

disposal.[10] Empirical studies show that firms associated with banks hit hard by the crisis reduced employment to a particularly high degree (e.g. Chodorow-Reich 2014; Hubbard 1998). Thus, it could be expected that firms would rather reduce labor than reallocate it to innovation in the case of a negative shock to financing in the recent financial crisis. Accordingly, we hypothesize that firms are more likely to reallocate excess resources like labor to the innovation department if the firm faces lower bank financing constraints (i.e. higher bank loan growth) in the financial crisis.

H3: Firms related to a bank with higher credit supply growth are more likely to reallocate resources like labor to the innovation department.

It remains questionable whether firms solely adjust their innovation in the short run or put higher emphasis on specific long-run strategies to cope with the consequences of the financial crisis. As the decision on their strategy is made when engaging in innovation (e.g. Levinthal & March 1993; March 1991; Tushman & O'Reilly 1996), it could be questioned whether the credit supply reduction during financial crisis led to the adoption of a specific innovation strategy. This is of particular interest, as the innovation strategy is important for the success of innovation (Gary 2005; Burgelman et al. 2008) as well as the survival and growth of firms (Guan et al. 2009). Moreover, the strategic decision of the firm might imply that it is pursuing a specific action to survive the crisis.[11] Additionally, the choice of a specific firm strategy influences the capital structure of the firm (e.g. Balakrishnan & Fox 1993; Kochhar & Hitt 1998) and the type of financing that can be obtained (e.g. Hellmann & Puri 2000).

As the environment in a financial crisis is rather uncertain (Wan & Yiu 2009), firms might react to the threatening situation by placing more emphasis on cost reduction strategies (Kunc & Bhandari 2011). However, similarly to the argument made above, this might not hold if there is enough external financing at hand. With respect to product innovation, firms might adopt specific product innovation strategies to increase their market share if there are enough financial resources available (Hambrick & Snow 1977; Moses 1992; Nohria & Gulati 1996). In contrast, firms with a shortage of external financing resources probably cannot afford to introduce new products. It might be argued that financially constrained firms in general adopt more conservative innovation strategies (e.g. Nanda & Nicholas 2014) or even abstain from innovation.[12] This is rooted in the fact that innovation activities are immediate-term expenses with the chance of increasing profits only in the long term. Thus, if survival is in danger, the long run is probably irrelevant. Consequently, it could be expected that firms adjust their innovation strategy during the financial crisis in correlation with the credit supply of their main bank.

[10] See e.g. Nohria & Gulati (1996) for a discussion and analysis of the impact of slack resources on innovation.

[11] Rust et al. (2002) show a relation between quality-improving strategies which aim at cost reduction or revenue expansion (i.e. by innovation) and firm performance.

[12] This might not least be rooted in the fact that having too few resources at hand might distort the firm's incentive to perform rather experimental projects (e.g. Nohria & Gulati 1996).

H4: A firm's adjustments to its innovation strategy during the financial crisis depend on the credit supply of its main bank.

4.3 Data and empirical strategy

4.3.1 Data and variables

To investigate the transmission of specific bank shocks on the innovation activities of their corporate customers, we use the 2010 wave of the Mannheim Innovation Panel (MIP) in combination with bank balance sheet data from Bankscope. The MIP represents the German section of the European CIS Survey.[13] It has been conducted annually since 1993 and focusses on the innovation activities of firms. Besides general firm information, the survey includes data on the innovative nature of firms. Thus, the MIP comprises information about innovation activities as well as special sections regarding, for example, the financing of innovation. The MIP 2010 wave includes a specific section on the consequences of the financial crisis on innovation and this allows us to identify the effects of the negative shock to bank credit supply on firms' innovative activity during the crisis. In addition, we are able to identify each firm's main bank with which it has commercial relations on a continuous basis. Applying a German bank identification code, we compile a data set that consists of firm data from the MIP and bank balance sheet information for the firm's main bank. Data for bank balance sheet information are obtained from the Bankscope database which is distributed by Bureau van Dijk. Additionally, Bankscope also provides data regarding the deposit structure of banks.[14] Applying this matching procedure leads to our final sample which consists of 1465 non-financial firms. Our sample includes firms from the manufacturing industry (NACE Rev. 2.0 divisions 5 to 39) and the knowledge-intensive services (NACE Rev. 2.0 divisions 58 to 66 and 69 to 73). With respect to the sampled firms in the MIP, these industries account for roughly all firms except for those which are active in the non-knowledge-intensive services.[15]

To construct the outcome variables necessary to answer our main research question, we use a unique item from the MIP survey in 2010 which surveys managers' evaluation of the consequences of the financial crisis on innovation by posing the following question: "In 2009, did your company implement the following changes to its innovation activities as a result of the economic crisis?". To test for hypothesis H1, we first utilize the subsequent yes-no question: "Reduction of innovation activities due to funding shortages". The resulting dummy variable 'Reduction of innovation activities' takes unit value if the firms answered the question in the affirmative and zero if not. In addition, we consider

[13] See e.g. Rammer (2012) for a technical summary of the MIP wave 2010 and Aschhoff et al. (2013) for a technical summary of the MIP waves 2007, 2009 and 2011.

[14] For private banks, headquarter balance sheet information is applied.

[15] Table 4.10 of Appendix 4.7.1 shows the distribution of firms over the industries.

two yes-no questions on the initiation of innovation activity in 2009 due to the financial crisis. The first question is on additional product innovation or services: "Initiation of additional innovation activities to introduce new products / services". It is followed by information collection on process innovation: "Initiation of additional innovation activities to introduce new / improved processes". We create two dummies, 'Initiation of product innovation' and 'Initiation of process innovation'. Unit value is assigned if the companies answer the questions affirmatively and zero if this is not the case. Besides testing for hypothesis H1, these two questions allow for testing hypothesis H2 concerning the initiation of product or process innovation.

Furthermore, the following yes-no question on the reallocation of human resources to increase innovation capacity is included: "Use of free human resources for increased innovation activities" to test for hypothesis H3. We create the variable 'Reallocation of human resources to innovation' and assign unit value if the firm undertook this measure and zero if not. For the test concerning any changes in innovation strategy (hypothesis H4), the following question concerning strategic changes is utilized: "Which impact do the following strategic actions in response to changes in economic conditions have on your company?" with the sub-items "Reduction of production/service costs", "Renewal of existing production and service offers" and "Extension of supply to new market segments/ customer groups" which are measured on a four point scale from no impact to high impact.

We also have access to several firm-specific variables as of 2009 which serve as control variables. The baseline explanatory variables include standard variables such as the logarithm of age 'Log of Firm age', size measured by the logarithm of the number of employees 'Log of Employees', and its square 'Log of Employees squared' and membership to a group of firms 'Part of firm group'. Additionally, a rating index 'Firm rating' is included to represent risks associated with the individual companies.[16] The index is computed by Creditreform, the leading credit rating agency in Germany. A higher value of the 'Firm rating' index indicates a higher probability of default by a particular firm. This variable reflects the internal financial situation as well as access to external financing (e.g. Czarnitzki & Hottenrott 2011a; Czarnitzki & Hottenrott 2011b). Using the credit rating indicator, we also account for the fact that the firm rating gained more importance due to the Basle II accord.[17]

Moreover, we control for potential demand effects in specific regions and industries. However, the argument could be raised that demand effects do not play a large role in Germany as the economy was in good standing before the crisis and the changes in

[16] We impute missing rating observations by lagged rating values. See e.g. Czarnitzki & Toole (2011) for a similar approach.

[17] The average rating value of the firms in our sample is about 227. This 'good' rating is above values which are presented in studies utilizing the credit rating index for pre-crisis time periods (e.g. Czarnitzki & Hottenrott 2011a; Czarnitzki & Hottenrott 2011b). Moreover, a rating of 227 coincides with the medium financial strength category applied in Peters et al. (2017). In addition, the average rating value in our sample corresponds to the mean rating value which is shown in Hud & Hussinger (2015), who also investigate the crisis period.

economic conditions (e.g. unemployment) were moderate compared to other economies (e.g. OECD 2010; OECD 2012). Nevertheless, we follow works like Cingano et al. (2016), De Jonghe et al. (2019), Degryse et al. (2019) and Dwenger et al. (2018) and deal with this issue by including industry times federal state fixed effects.

In addition, we specify a set of dummy variables based on a question concerning the significance of reduced profits or increased losses as a consequence of the crisis of 2008/2009: "Which impact did the following consequences of the economic crisis 2008/2009 have for your company?" with the sub-item "Decrease in profits respectively increase in losses". This question allows for a direct assessment of the dependence on and availability of internal financing. The resulting dummy variables are called 'High influence of profit reduction', 'Med influence of profit reduction', 'Low influence of profit reduction' and have unit value if the firm evaluated the importance of the profit reduction as high, medium or low. Assigning no importance at all to profit reduction serves as the base category. We construct a similar set of variables for the sub-item "Decrease in sales". This is an additional control variable to account for the impact of demand on the firm.

Due to our data matching, we are able to utilize bank balance sheet information from the Bankscope database.[18] As we want to investigate the impact of a bank credit supply shock on firm innovation activities, we follow works like Dwenger et al. (2018) and use the loans the bank grants to all of its customers. This variable covers the full loans provided by the bank and therefore allows us to determine to what extent banks adjusted them. The impact of the crisis was greatest in 2009 (e.g. Bundesbank 2009; IMF 2016) such that the change in loans from 2008 to 2009 covers the extent to which the bank was affected by the turmoil on financial markets. Consequently, we generate the variable $\Delta\text{Credit\_Supply}_{ij}$ which measures the growth in bank credit supply from 2008 to 2009.[19]

In addition to the loan information, we are able to exploit the interbank market usage of banks. Following Cingano et al. (2016) and Iyer et al. (2014), we calculate the share of interbank market borrowing to total bank assets 'Interbank' as the measure for interbank market dependence of banks. We take the resulting figure as of 2006, before the financial crisis emerged. This variable is subsequently applied to account for the influence of the financial crisis on the relevance of interbank borrowing in relation to total assets. Descriptive statistics for our baseline sample are shown in Table 4.1.

[18] In 2009, the Dresdner Bank and Commerzbank merged. Since we do not want to create a selection problem by dropping those observations, we deal with their merger by aggregating the pre-merger balance sheet positions of both banks for continuous variables. See e.g. Huber (2018) for a similar approach.

[19] We present additional definitions of the change in credit supply in the robustness test Section 4.5.3. These cover the change from the year 2007 to 2008 as well as the change from 2007 to 2009.

Table 4.1: Descriptive statistics

	Description	Mean	SD	Median
Dependent variables				
Innovation reduction	Indicator variable whether 'Reduction of innovation activities' is answered in the affirmative or not	0.201	0.401	0
Product innovation	Indicator variable whether 'Initiation of additional innovation activities to introduce new products / services' is answered in the affirmative	0.448	0.498	0
Process innovation	Indicator variable whether 'Initiation of additional innovation activities to introduce new / improved processes' is answered in the affirmative	0.440	0.497	0
Labor reallocation	Indicator variable whether 'Use of free human resources for increased innovation activities' is answered in the affirmative	0.272	0.445	0
Product / service cost reduction	Impact of the strategic action 'Reduction of production/ service costs' in response to the financial crisis	2.151	0.959	2
Production and offer renewal	Impact of the strategic action 'Renewal of existing production and service offers' in response to the financial crisis	1.703	0.995	2
Extension of supply to new markets	Impact of the strategic action 'Extension of supply to new market segments / customer groups' in response to the financial crisis	1.986	0.977	2
Firm variables				
Employees	Number of employees measured in thousands	0.269	1.277	0.040
Firm age	Firm age in years	29.532	32.745	18
Group	Indicator variable whether the firm is part of a firm group	0.451	0.498	0
Firm rating	Rating index	227.042	50.601	222
Impact of profit reduction	Variable that indicates the impact of a decrease in profits or increase in losses in the economic crisis 2008/2009 on the company	1.743	1.162	2
Impact of decrease in sales	Variable that indicates the impact of a decrease in sales in the economic crisis 2008/2009 on the company	1.715	1.154	2
Bank balance sheet information				
Interbank	Ratio of interbank borrowing to total assets as of 2006	0.255	0.117	0.298
Credit_Supply	Bank growth of credit from 2008 to 2009	−0.044	0.177	−0.020

4.3.2 Empirical strategy

We are interested in measuring the impact of changes in the loan supply of banks during the financial crisis on the innovation behavior of firms. Thus, the relationship between bank loan growth and innovation activity might be described as follows

$$\text{Innovation}_i = \beta_0 + \beta_1 \Delta\text{Credit\_Supply}_{ij} + \beta_k X_{k,i} + \eta_i + \varepsilon_i \tag{4.1}$$

Where Innovation_i represents the above-mentioned outcomes: reducing innovation expenditures due to funding shortages during the financial crisis, initiating new product or process innovations or reallocating of human resources to innovation. The variable $\Delta\text{Credit\_Supply}_{ij}$ comprises the loan growth of a firm's main bank in 2009. Moreover X_k consists of several firm-specific variables as described above and η_i is a set of industry times federal state dummies. The error term is described by ε_i.

The presented specification (4.1) does not allow a causal interpretation, because a feedback effect might be present, as the left- and right-hand side variables might be determined by some common yet omitted variables (e.g. innovation or investment opportunities). Moreover, we do not have information on the specific bank loans which are transmitted from bank j to firm i but just the general bank lending growth of bank j. Thus, the variable reflects the individual loans granted to firms measured with an error. Next, the financial strength of firms might not be independent from the credit growth of banks such that the credit supply coefficient would not inform us about the effect of the change in lending. In order to identify the causal effect of debt on innovation, we need to instrument our variable of interest $\Delta\text{Credit\_Supply}_{ij}$.

As the financial crisis affected supply and demand, we use an instrumental variable which shifts the supply side of credit growth to detangle the effects of both sides of the debt market. Our instrumental variable is the interbank relation of the individual banks.[20] Problems with respect to asymmetric information concerning borrower quality prevail on the interbank market (e.g. Freixas & Holthausen 2005; Rochet & Tirole 1996). Consequently, disruptions on the interbank market affect liquidity distribution in the financial system and costs of funds negatively. The financial crisis of 2008/2009 marks a period of stress on financial markets which reached its peak with the breakdown of Lehman Brothers in late 2008 (Acharya & Merrouche 2012). After this event, the turmoil on the interbank market led to loss of trust between banks, resulting in sharply increased spreads, liquidity holding and – related with this – a much lower supply of financial resources (Acharya & Merrouche 2012; Acharya & Skeie 2011; Ashcraft et al. 2011) and in particular for Germany (Craig & Von Peter 2014 and IMF 2016). The Bundesbank (2009) and IMF (2016) point to the possible influence of disruptions on the interbank market on bank lending, and the Bundesbank (2009) presents descriptive evidence on lending reduction to non-financial

[20] See e.g. Norden & Weber (2010) for an overview of the funding modes of German banks.

firms. Moreover, empirical studies show the negative relation between a bank's interbank reliance and bank-firm lending for Portugal (Iyer et al. 2014) and Italy (Cingano et al. 2016). Consequently, we expect that higher interbank market borrowing activities prior to the crisis will exert a negative effect on bank lending during the crisis. It has to be noted that the interbank ratio is assumed not to be directly related to the innovativeness of firms. Firstly, the interbank market activities of banks are not based on the customer business as argued by Cingano et al. (2016). As the interbank market notion reveals, this kind of market is solely for the exchange of liquidity among banks. Moreover, as shown by Giebel & Kraft (2019), the interbank ratio did not exert any significant influence on firm innovation expenditures in the time prior to 2008.

Using this instrument, we apply the following two-stage estimation approach: To begin with, we run a first-stage OLS regression of $\Delta\text{Credit\_Supply}_{ij}$ on all variables from Equation (4.1) and the variable Interbank which is correlated with our endogenous variable $\Delta\text{Credit\_Supply}_{ij}$, and with the innovation decision only due to its relation to credit supply. In the second stage, we plug the predicted values of $\Delta\text{Credit\_Supply}_{ij}$ from the first-stage regression (4.2) into the Equation (4.1) which leads to Equation (4.3).[21]

$$\Delta\text{Credit\_Supply}_{ij} = \gamma_0 + \gamma_1 \text{Interbank}_{ij} + \gamma_k X_{k,i} + \eta_i + \mu_i \tag{4.2}$$

$$\text{Innovation}_i = \beta_0 + \beta_1 \widehat{\Delta\text{Credit\_Supply}}_{ij} + \beta_k X_{k,i} + \eta_i + \varepsilon_i \tag{4.3}$$

The suitability of our instrument is checked by inspecting the coefficients in the first stage with respect to sign and significance. Moreover, the F-test on instruments excluded from the second stage checks for the validity of the instrument. If the F-statistic exceeds a threshold value of 10, the instruments are assumed to be valid in terms of their influence on the endogenous variable (Staiger & Stock 1997).

4.4 Main results on bank credit supply and firm innovation

4.4.1 First stage results - Interbank market reliance and credit supply

We present the first stage estimation results (Equation (4.2)) in Table 4.2. Thus, we regress the credit growth variable on the Interbank to asset ratio as of 2006. As explained above, in the context of the crisis period, the negative sign of the (highly significant) Interbank coefficient is to be expected. In the first and second Columns of Table 4.2, we report the simple regression results without any control variables. Both coefficients show a reduction in credit supply by about 7 percent for a 10 percent increase in the interbank borrowing rate. Adding industry times state fixed effects did not alter the estimate remarkably. In Columns (3) and (4), we add firm controls and find that the estimates again do not change

[21] We report the usual two-stage least squares results (2SLS) from the Stata module `ivreg2` by Baum et al. (2010) which allows for instrument sensitivity tests.

by much. The F-value of 161.72 far exceeds the critical value of ten, indicating that our instrument is valid with respect to the influence on the endogenous variable.[22]

Table 4.2: The effect of interbank market borrowing on credit supply

Dependent variable	(1)	(2)	(3)	(4)
	Δ Credit_Supply			
Interbank	−0.664***	−0.706***	−0.637***	−0.675***
	(0.049)	(0.053)	(0.050)	(0.053)
Industry × federal state FE	No	Yes	No	Yes
Firm controls included	No	No	Yes	Yes
F-value of Interbank	181.97	169.96	156.75	161.72
R-squared	0.192	0.326	0.207	0.341
Observations	1465	1465	1465	1465

Notes: The dependent variable ΔCredit_Supply$_{ij}$ is constructed as the change in credit supply by banks from 2008 to 2009. The variable Interbank is calculated as the value of interbank borrowing to total assets of the firm's main bank as of 2006. Firm controls comprise Log of Employees and its square, Log of Firm age, a dummy for being part of a firm group, the firm's credit rating and dummies for the perception (Low, Medium, High) of the reduction in sales and the reduction in profits in the crisis. Heteroscedasticity-consistent standard errors are reported in parentheses. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

4.4.2 Reduced form results - Interbank market reliance and innovation

Next, we test whether the shock to the interbank market affects the innovation behavior of firms directly. Thus, we shed light on the reduced form estimates (Table 4.3), which are obtained by regressing the innovation outcome variables on the interbank market measure. The coefficient is positive and significant at the 1 percent level in Column (1). This indicates that a 10 percent increase in the interbank borrowing ratio increases the probability of reducing innovation activities due to funding shortages by about 3.1 percent. For the remainder of the outcome variables, we observe expected, negative effects of the interbank borrowing ratio. Although the coefficient is not significant at conventional levels for the initiation of process innovation in Column (3), the other coefficients are highly significant at the 1 percent level.[23]

We use the reduced form estimates to determine the aggregate effect of the interbank market shock on the innovation outcomes in our sample.[24] Firstly, we calculate the predicted probability of each firm to adjust the related outcome and assume that the counterfactual state is that a zero interbank market borrowing to asset ratio exerts no effect on innovation. Consequently, we simply multiply the coefficient of interbank with the average

[22]The F-test of the excluded instrument also exceeds the critical values shown in Stock & Yogo (2005). Thus, we conclude that it is not weak. See Stock & Yogo (2005) for further information on weak instruments.

[23]Reduced form estimates without industry times state fixed effects and/or without controls have a similar magnitude and significance. They are available upon request. See Appendix 4.7.2, Table 4.12 for the estimation of the reduced form relationship using a Probit model.

[24]Our approach to determine the aggregate impact follows Denk & Finkel (1992).

interbank market borrowing to asset ratio of the firms. For the reduction in innovation expenditures due to funding shortages in Column (1), which serves as our benchmark result, this calculation exercise (0.305×0.255) results in 0.078. Thus, a firm associated with the average bank is 7.8% more likely to reduce its innovation behavior due to funding shortages in the crisis than a firm related to a bank with zero interbank market usage. In the next step, we divide this predicted probability by the sample mean of the dependent variable to evaluate the economic impact. The result implies that the interbank market shock explains about 38.8% of the reduction in innovation due to funding shortages.

Similarly, we can calculate the aggregate impact of the bank credit supply shock on the initiation of product innovation and the reallocation of labor to the innovation department. For this purpose, we took the counter probability of each event to evaluate the foregone efforts. We find that about 31.75% of the reduction in product innovation and 25.18% of non-reallocations of labor to the innovation department are observed due to the interbank market shock. Consequently, the shock to the bank system significantly explains the innovation behavior of firms in the crisis.

Table 4.3: Linear regression for the effect of interbank market borrowing on immediate innovation adjustments

Dependent variable	(1) Innovation Reduction	(2) Product innovation	(3) Process innovation	(4) Labor reallocation
Interbank	0.305***	−0.317**	−0.195	−0.385***
	(0.099)	(0.125)	(0.126)	(0.121)
R-squared	0.258	0.229	0.199	0.171
Observations	1465	1465	1465	1465

The dependent variables are indicator variables concerning the changes in the firm's innovation behavior as of 2009. 'Innovation Reduction' takes unit value if the firm has reduced its innovation activities due to funding shortages in 2009. 'Product innovation' marks the initiation of an additional product innovation. 'Process innovation' is similarly constructed for process innovation. 'Labor reallocation' takes unit value if the firm reallocated free human resources to the innovation department. The variable Interbank is calculated as the value of interbank borrowing to total assets of the firm's main bank as of 2006. Each regression includes the following firm controls as described in Section 4.3.1: Log of Employees and its square, Log of Firm age, a dummy for being part of a firm group, the firm's credit rating and dummies for the perception (Low, Medium, High) of the reduction in sales and the reduction in profits in the crisis. Each regression includes industry times federal state fixed effects. Heteroscedasticity-consistent standard errors are reported in parentheses. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

4.4.3 Instrumental variable estimations

Finally, we focus on the instrumental variable estimations. Results of the usual 2SLS estimation are given in Columns (1) to (4) in Table 4.4.[25] We begin by analyzing the

[25]Results for an estimation method which accounts for the binary nature of the dependent variable are shown in Appendix 4.7.2, Table 4.13. The results are comparable. Moreover, this approach includes a test

impact of bank loan growth on the reduction of innovation activities during the crisis due to funding shortages (H1). The coefficient of the loan growth variable is negative and highly significant at the one percent level. This indicates that higher loan growth leads to a lower probability of reducing innovation activities. The linear marginal effect reveals that a ten-percentage-point decrease in loan growth leads to an increase in the probability of reducing innovation activities due to funding shortages during the crisis by about 4.5 percentage points. Moreover, the coefficient of interest in Column (2) is significant at the five percent level. The effect implies that an increase in loan growth by ten percentage point leads to a 4.7 percentage point higher probability of initiating a product innovation (Column 2). With respect to the initiation of process innovation, we also find a positive effect which is not significant at conventional levels. Thus, firms react sensitively with respect to bank credit supply solely for the initiation of product innovation. This partly supports Hypothesis 2. Thus, apparently during the crisis new product developments are initiated if external financial resources are available, but projects that serve cost savings by new processes are not affected. Lastly, we analyze the behavior of firms with respect to the alternative allocation of labor in correlation with their main bank's loan growth. Our hypothesis 3 gets empirical support, as a ten percent higher bank loan growth induces a 5.7 percentage point increase in the likelihood of reallocating human resources to innovation in the crisis.

for the endogeneity of the ΔCredit_Supply$_{ij}$ variable. The test reveals that instrumenting is the correct choice.

Table 4.4: Instrumental variable estimation results for the immediate innovation adjustments

Dependent variable	(1) Innovation Reduction	(2) Product innovation	(3) Process innovation	(4) Labor reallocation
ΔCredit_Supply	−0.452***	0.470**	0.288	0.570***
	(0.153)	(0.187)	(0.188)	(0.187)
Log of Employees	−0.063**	0.048	0.067*	0.049
	(0.031)	(0.038)	(0.038)	(0.031)
Log of Employees squared	0.006*	−0.007*	−0.006	−0.005
	(0.003)	(0.004)	(0.004)	(0.003)
Log of Firm age	−0.008	−0.043**	−0.050**	−0.057***
	(0.016)	(0.019)	(0.020)	(0.018)
Part of firm group	−0.005	−0.021	0.039	−0.029
	(0.027)	(0.033)	(0.034)	(0.031)
Low influence of sales reduction	0.007	0.116**	0.115*	0.102*
	(0.044)	(0.059)	(0.060)	(0.058)
Med influence of sales reduction	0.100**	0.128**	0.089	0.120**
	(0.050)	(0.062)	(0.062)	(0.061)
High influence of sales reduction	0.119**	0.218***	0.124*	0.148**
	(0.055)	(0.068)	(0.068)	(0.066)
Low influence of profit reduction	0.003	−0.065	−0.102*	−0.005
	(0.044)	(0.060)	(0.059)	(0.058)
Med influence of profit reduction	0.051	−0.040	0.001	0.004
	(0.047)	(0.062)	(0.061)	(0.060)
High influence of profit reduction	0.169***	−0.102	−0.025	0.034
	(0.056)	(0.067)	(0.067)	(0.065)
Firm rating	0.001***	−0.001***	0.000	−0.001**
	(0.000)	(0.000)	(0.000)	(0.000)
R-squared	0.218	0.208	0.188	0.115
Observations	1465	1465	1465	1465

The dependent variables are indicator variables concerning the changes in the firm's innovation behavior as of 2009. 'Innovation reduction' takes unit value if the firm has reduced the innovation activities due to funding shortages in 2009. 'Product innovation' marks the initiation of an additional product innovation. 'Process innovation' is similarly constructed for process innovation. 'Labor reallocation' takes unit value if the firm reallocated free human resources to the innovation department. The variable of interest, ΔCredit_Supply is constructed as the change in credit supply by banks from 2008 to 2009. Each regression includes industry times federal state fixed effects. Heteroscedasticity-consistent standard errors are reported in parentheses. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

4.4.4 Effect on firm strategy

Next, we test for the firm's perception of the impact of innovation related strategy in reaction to the crisis, depending on bank credit supply. For this purpose, we again exploit our survey data such that we utilize questions which ask for the importance of strategic actions in response to changes in economic conditions during the crisis: "Which impact do the following strategic actions in response to changes in economic conditions have on your company?". We pick three commonly used (e.g. Archibugi et al. 2013a) innovation-related items: "Reduction of production/service costs", "Renewal of existing production and service offers" and "Extension of supply to new market segments / customer groups".

Answers were possible on a four-point Likert scale from "no importance" to "high importance". As a strategic action is more likely to be a long-term change, our test informs us whether the change in bank credit supply also affects the emphasis on long-term strategic actions of firms. The results of linear regressions in Table 4.5 reveal that neither opportunity is affected by the change in credit supply.[26]

Table 4.5: Instrumental variable estimations for the effects on firm strategy

Dependent variable	(1) Product / service cost reduction	(2) Production and offer renewal	(3) Extension of supply to new markets
ΔCredit_Supply	0.021	0.236	0.441
	(0.335)	(0.369)	(0.351)
Log of Employees	0.286***	0.125*	0.124
	(0.065)	(0.076)	(0.079)
Log of Employees squared	−0.017***	−0.008	−0.013
	(0.006)	(0.008)	(0.008)
Log of Firm age	−0.035	−0.072*	−0.011
	(0.032)	(0.038)	(0.035)
Part of firm group	0.114*	−0.025	0.080
	(0.059)	(0.066)	(0.066)
Low influence of sales reduction	0.227**	0.147	−0.083
	(0.110)	(0.117)	(0.115)
Med influence of sales reduction	0.384***	0.206*	0.064
	(0.117)	(0.122)	(0.124)
High influence of sales reduction	0.507***	0.325**	0.106
	(0.124)	(0.133)	(0.130)
Low influence of profit reduction	−0.014	0.037	0.151
	(0.114)	(0.120)	(0.118)
Med influence of profit reduction	0.235**	0.077	0.259**
	(0.114)	(0.122)	(0.121)
High influence of profit reduction	0.298**	0.066	0.350***
	(0.123)	(0.133)	(0.131)
Firm rating	−0.001	−0.001	0.000
	(0.000)	(0.001)	(0.001)
R-squared	0.356	0.237	0.218
Observations	1465	1465	1465

The dependent variables are indicator variables concerning the changes in the firm's innovation behavior as of 2009. 'Cost reduction' is a four-point scale variable which indicates the impact (None, Low, Average, High) of pursuing a production/service cost reduction strategy to cope with the changing economic conditions during the crisis. 'Offer renewal' and 'Extension of supply to new markets' are constructed similarly for the questions of the impact of the renewal of existing production and service offers and the extension of supply to new market segments/ customer groups. The variable of interest, ΔCredit_Supply is constructed as the change in credit supply by banks from 2008 to 2009. Each regression includes industry times federal state fixed effects. Heteroscedasticity-consistent standard errors are reported in parentheses. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

[26]We conduct additional tests which reinforce the results in Table 4.5. We find that there is no impact of the bank credit supply shock on the innovation strategy choice (i) conditional on being affected by the crisis (or not), (ii) conditional on taking any short-term innovation adjustment. Results for these tests are available upon request. Using a two-stage ordered Probit estimation approach does not alter the results (Appendix 4.7.5, Table 4.18). Additional tests with dummy variables indicating at least medium importance to any mere leads to similar results.

4.5 Robustness tests and extensions

4.5.1 Possible endogenous matching of firms and banks

A potential concern with respect to our identification strategy might be our assumption of a random affiliation of banks and their corporate customers. Firstly, the argument might be raised that innovative (high-risk) firms match with banks whose business model is based on funding this kind of firms. Thus, the observed effect on innovation would be rather due to a correlation of the reduction of risky activities by banks and firms in the downturn than due to the negative shock to bank credit supply. Secondly, it might be the case that firms' financial strength in the downturn is highly related to their banks' exposure to the interbank market shock. In this case, banks with a higher probability of experiencing an interbank liquidity shortage would be related to firms which are more likely to experience worse economic outcomes in economic downturns. Hence, the possibility of a selectivity problem exists such that our estimates rather reflect endogenous matching than a causal effect. If this were the case, our identification strategy would be invalid and the estimation results biased.

We use a re-weighting approach to tackle the possible selectivity problem. To do so, we follow the two-step methodology proposed by Imbens & Wooldridge (2009) as well as Abadie & Cattaneo (2018): First, we estimate the probability of each firm to be treated (the propensity score). Treatment status is defined as being related to a bank in the upper quartile of the interbank distribution.[27] Then, we replicate our regressions of Table 4.3 and weight each observation by an inverse probability weight, generated from its propensity score.[28] The re-weighting is supposed to equalize the two firm types with respect to the explanatory variables. Consequently, potential differences between the two firm types would be eliminated.

Taking the inverse-probability weights, we re-estimate the specifications whose results are presented in Table 4.6. If the hypothesis of a sorting of firms and banks according to risk preferences and financial strength is true, our re-weighting approach would lead to drastically different results. The coefficients in Table 4.6 indicate that the results are comparable to the baseline results in Table 4.4. Interestingly, the credit supply coefficient is now significant at the five percent level for the initiation of additional process innovation.

[27] The results are similar when defining firms as treated when they are related to a bank in the upper 10% or 50% of the interbank distribution. Results are available upon request.

[28] Appendix 4.7.3 covers results of the propensity score estimation (Table 4.14) and mean comparison after the re-weighting (Table 4.15). Restricting the sample to common support leads to a loss of 3 observations.

Table 4.6: Re-weighted instrumental variable regressions

Dependent variable	(1) First stage	(2) Innovation Reduction	(3) Product innovation	(4) Process innovation	(5) Labor reallocation
ΔCredit_Supply		−0.447***	0.589***	0.467**	0.580***
		(0.168)	(0.197)	(0.197)	(0.189)
Interbank	−0.659***				
	(0.052)				
R-squared	0.377	0.256	0.252	0.234	0.177
Observations	1462	1462	1462	1462	1462

The dependent variables are indicator variables concerning the changes in the firm's innovation behavior as of 2009. 'Innovation reduction' takes unit value if the firm has reduced its innovation activities due to funding shortages in 2009. 'Product innovation' marks the initiation of an additional product innovation. 'Process innovation' is similarly constructed for process innovation. 'Labor reallocation' takes unit value if the firm reallocated free human resources to the innovation department. The variable of interest, ΔCredit_Supply is constructed as the change in credit supply by banks from 2008 to 2009. The variable Interbank is calculated as the value of interbank borrowing to total assets of the firm's main bank as of 2006. Each regression includes the following firm controls as described in Section 4.3.1: Log of Employees and its square, Log of Firm age, a dummy for being part of a firm group, the firm's credit rating and dummies for the perception (Low, Medium, High) of the reduction in sales and the reduction in profits in the crisis. Each regression includes industry times federal state fixed effects. Heteroscedasticity-consistent standard errors are reported in parentheses. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

4.5.2 Demand effects

In addition to the inclusion of industry-federal state fixed effects, we employ a second test to alleviate the demand effect concerns. The idea is to make the firms from specific industries and geographic areas as similar as possible such that only the difference in the firm's main bank interbank market reliance persists. This allows us to investigate whether the effect is due to the interbank market shock or due to the characteristics of firms and banks. We approach this test as follows: We keep only firms in the bottom and the top quartile of the interbank borrowing to asset ratio distribution such that our sample is restricted to 735 observations. Next, we use two different approaches to make the firms as similar as possible such that only the effect of the shock remains. Firstly, we estimate the probability of being in the top quartile and re-weight the instrumental variable estimations by the calculated inverse-probability weight. Results of this exercise (non-weighted and weighted) are shown in Table 4.7, Panels A and B. These are quite similar to the results presented above. Additionally, we observe that the coefficients are slightly larger in absolute terms. Again, the significance of the coefficient for process innovation reveals there is an impact of the change in credit supply on the initiation of this innovation type.

Secondly, we want to account for industry- and region-specific firm bank matches. The aim of this exercise is to compare a firm with high interbank exposure to a similar firm with low interbank exposure in a similar geographic area and industry. Consequently, the shock effect becomes most important. For this purpose, we use the information on research-intensive industries by Gehrke et al. (2013) to sort the firms into high research intensity,

medium to low research intensity and irregular to no research activity. For the regional information, we use the information for federal states from Statistisches Bundesamt (2008). We construct four bins according to the share of sales per firm in the federal states. Combining this information leads to 12 groups of firms which are in similar regions and industries. To conduct the empirical test, we first calculate a propensity score for the group of firms in each category based on their size and firm rating. In a second step, we search for the nearest neighbor for each firm in the specific category.[29] Lastly, we apply our estimation approach only to the matched pairs. If our hypothesis of an interbank market-related shock on innovation activities is true, we expect to observe diverging innovation outcomes for both types of firms in both approaches. The results in Table 4.7, Panel C show that we indeed observe significantly different outcomes.[30] Consequently, we can rule out that demand effects are driving our results.

Table 4.7: Instrumental variable estimation results for tests concerning demand effects

Dependent variable	(1) First stage	(2) Innovation Reduction	(3) Product innovation	(4) Process innovation	(5) Labor reallocation
Panel A: Top and bottom 25% (N= 735)					
ΔCredit_Supply		−0.546***	0.496**	0.404	0.678***
		(0.207)	(0.246)	(0.245)	(0.252)
Interbank	−0.609***				
	(0.065)				
Panel B: Top and bottom 25%, re-weighted (N= 726)					
ΔCredit_Supply		−0.551***	0.561**	0.469**	0.697***
		(0.199)	(0.236)	(0.233)	(0.240)
Interbank	−0.617***				
	(0.062)				
Panel C: Top and bottom 25%, matched pairs (N= 620)					
ΔCredit_Supply		−0.780***	0.893***	0.540**	0.551**
		(0.226)	(0.264)	(0.249)	(0.258)
Interbank	−0.617***				
	(0.079)				

The dependent variables are indicator variables concerning the changes in the firm's innovation behavior as of 2009. 'Innovation reduction' takes unit value if the firm has reduced the innovation activities due to funding shortages in 2009. 'Product innovation' marks the initiation of an additional product innovation. 'Process innovation' is similarly constructed for process innovation. 'Labor Reallocation' takes unit value if the firm reallocated free human resources to the innovation department. The variable of interest, ΔCredit_Supply is constructed as the change in credit supply by banks from 2008 to 2009. The variable Interbank is calculated as the value of interbank borrowing to total assets of the firm's main bank as of 2006. Coefficients reflect the estimates for ΔCredit_Supply for each subgroup. Each regression includes the following firm controls as described in Section 4.3.1: Log of Employees and its square, Log of Firm age, a dummy for being part of a firm group, the firm's credit rating and dummies for the perception (Low, Medium, High) of the reduction in sales and the reduction in profits in the crisis. Each regression includes industry times federal state fixed effects. Heteroscedasticity-consistent standard errors are reported in parentheses. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

[29] We allow for a maximum acceptable difference between treatment and control observations (Caliper) of 0.05. Our caliper choice is below the caliper of 0.25 times the standard deviation of the propensity score as suggested by Rosenbaum & Rubin (1985).

[30] Results of the Probit estimation to determine the propensity score are shown in Appendix 4.7.4, Table 4.16. The comparison of means between treatment and control group after the re-weighting are given in Appendix 4.7.4, Table 4.17.

4.5.3 Crisis period refinement

In a further test we want to rule out that our results are driven by the measurement of the outcome variable. A valid argument might be that the innovation investments in firms are planned at least a year before the project starts. Thus, we apply the following two tests. First we re-estimate our baseline regressions using the credit growth from 2007 to 2008. Secondly, we use the credit growth from 2007 to 2009 to validate our results. The estimations using the described outcome variables are shown in Table 4.8, Panels A and B. It becomes evident that the refinement of the crisis period does not substantially affect our results. Consequently, the firms exposed to the shock adjust their innovation behavior due to the change in credit supply.

Table 4.8: Instrumental variable estimation results for different crisis period definitions

Dependent variable	(1) First stage	(2) Innovation Reduction	(3) Product innovation	(4) Process innovation	(5) Labor reallocation
Panel A: 2007-2008 credit growth in the first stage					
ΔCredit_Supply		−0.633***	0.658**	0.404	0.797***
		(0.217)	(0.262)	(0.262)	(0.258)
Interbank	−0.482***				
	(0.040)				
Panel B: 2007-2009 credit growth in the first stage					
ΔCredit_Supply		−0.280***	0.291**	0.179	0.353***
		(0.094)	(0.115)	(0.116)	(0.114)
Interbank	−1.090***				
	(0.071)				

The dependent variables are indicator variables concerning the changes in the firm's innovation behavior as of 2009. 'Innovation Reduction' takes unit value if the firm has reduced the innovation activities due to funding shortages in 2009. 'Product innovation' marks the initiation of an additional product innovation. 'Process innovation' is similarly constructed for process innovation. 'Labor Reallocation' takes unit value if the firm reallocated free human resources to the innovation department. The variable of interest, ΔCredit_Supply is constructed as the change in credit supply by banks as given in the title of each panel. The variable Interbank is calculated as the value of interbank borrowing to total assets of the firm's main bank as of 2006. Each regression includes the following firm controls as described in Section 4.3.1: Log of Employees and its square, Log of Firm age, a dummy for being part of a firm group, the firm's credit rating and dummies for the perception (Low, Medium, High) of the reduction in sales and the reduction in profits in the crisis. Each regression includes industry times federal state fixed effects. Heteroscedasticity-consistent standard errors are reported in parentheses. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

4.5.4 Effect heterogeneity

In addition to the previous robustness tests, we analyze the heterogeneity of our results. As argued in Section 4.2, we expect that firms react more sensitive to bank financing if they are directly affected by the recession and therefore face a lack of internal resources. By testing this hypothesis, we shed additional light on the question whether external financing in terms of bank credit supply affects firm innovation behavior independent of

the access to internal resources. As argued above, we expect that this is not the case. Consequently, we assume that the impact of bank credit supply is stronger for firms which face a reduction in demand or scarce internal means.[31] Moreover, this exercise serves as a placebo test as from a theoretical point of view as there should be no impact on the probability to reduce innovation activities due to funding shortages for firms which were not affected by the reduction in internal means.

We exploit our survey data such that we use a variety of indicators to differentiate between firms which are more or less affected by the recession and the effects of the financial crisis. Results for these tests are displayed in Table 4.9. Firstly, we differentiate our sample into firms which experienced a sales reduction in 2009 and those who did not. Our expectation is approved as the sensitivity to bank credit supply is apparently more prone in the sample of firms which faced a sales reduction in 2009. Interestingly, the credit supply coefficient in Column (3) is now weakly significant. This indicates that an increase in bank credit supply leads to an enhanced probability of the initiation of a process innovation.

In a second set of tests, we split the firms according to their sensitivity to changes in (i) a sales reduction and (ii) profit reduction due to the crisis. The question was asked as follows: "Which impact did the following consequences of the economic crisis 2008/2009 have for your company?" and includes the sub-items "Decrease in sales" and "Decrease in profits respectively increase in losses". Both questions were asked on a 4 point Likert scale from not sensitive to highly sensitive. We build a group of rather constraints and rather unconstraint firms from each indicator. The rather constraint group of firms consists of those, which indicate a high or medium impact of the respective variable. The unconstraint group comprises firms which answer that the respective effect has a low or none impact. The results for the split among these groups are shown in Panel B and C of Table 4.9. For the group of more constrained firms, the credit supply of banks has an impact on the propensity to reduce innovation or to initiate new product innovation. For process innovation there is a statically significant coefficient only for firms which perceive a high or medium influence of the decrease in sales. Interestingly, for the unconstrained firms, we find no impact of the supply of credit except for the effect of credit supply on the reallocation of labor to the innovation department. These firms are financially sound and might reallocate their internal resource streams in their firm to strengthen their current innovation activities.

Additionally, we add up the values of the decrease in sales and profit measures and split the sample at the median. The lower part of the distribution is declared as low sensitivity and the upper part as high sensitivity. The results for estimations for both groups of firms independently are shown on Panel D of Table 4.9. Remarkably, the results are also fairly

[31] See e.g. Hahn & Lee (2009) for a discussion on the difference between the impact of debt for constrained and unconstrained firms with respect to expected stock returns.

similar to the previous tests and the exercise using zero sales reduction as splitting point. Thus, internally constrained firms react more sensitively to the credit supply of banks in the financial crisis. This might imply an additivity of bank financing.

Table 4.9: Instrumental variable estimation results split into subsamples of constrained and unconstrained firms

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Constraint				**Unconstraint**			
Dependent variable	Innovation Reduction	Product innovation	Process innovation	Labor reallocation	Innovation Reduction	Product innovation	Process innovation	Labor reallocation
Panel A: Sales growth 2008 to 2009								
	Sales reduction (N=720)				*No sales reduction (N=426)*			
ΔCredit_Supply	−0.906***	0.596*	0.529*	0.488	0.228	0.210	0.279	0.204
	(0.285)	(0.311)	(0.316)	(0.310)	(0.288)	(0.412)	(0.396)	(0.411)
Panel B: Sensitivity to decrease in sales								
	Medium-High sensitivity (N=874)				*None-Low sensitivity (N=591)*			
ΔCredit_Supply	−0.980***	0.607**	0.572*	0.435	−0.163	0.165	−0.291	0.562*
	(0.276)	(0.298)	(0.302)	(0.295)	(0.159)	(0.279)	(0.298)	(0.297)
Panel C: Sensitivity to decrease in profits								
	Medium-High sensitivity (N=872)				*None-Low sensitivity (N=593)*			
ΔCredit_Supply	−0.834***	0.510*	0.369	0.282	−0.229	0.333	0.028	0.681**
	(0.270)	(0.293)	(0.294)	(0.291)	(0.162)	(0.292)	(0.296)	(0.287)
Panel D: Sensitivity to changes in internal means								
	High sensitivity (N=813)				*Low sensitivity (N=652)*			
ΔCredit_Supply	−1.082***	0.728**	0.589*	0.429	−0.102	0.203	−0.114	0.584**
	(0.302)	(0.314)	(0.316)	(0.316)	(0.150)	(0.264)	(0.274)	(0.267)

The dependent variables are indicator variables concerning the changes in the firm's innovation behavior as of 2009. 'Innovation reduction' takes unit value if the firm has reduced the innovation activities due to funding shortages in 2009. 'Product innovation' marks the initiation of an additional product innovation. 'Process innovation' is similarly constructed for process innovation. 'Labor reallocation' takes unit value if the firm reallocated free human resources to the innovation department. The variable of interest, ΔCredit_Supply is constructed as the change in credit supply by banks from 2008 to 2009. Each regression includes the following firm controls as described in Section 4.3.1: Log of Employees and its square, Log of Firm age, a dummy for being part of a firm group, the firm's credit rating and dummies for the perception (Low, Medium, High) of the reduction in sales and the reduction in profits in the crisis. Each regression includes industry times federal state fixed effects. Coefficients reflect the estimates for ΔCredit_Supply for each subgroup. Heteroscedasticity-consistent standard errors are reported in parentheses. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

4.6 Conclusion

We provide evidence for the existence of a relationship between the credit supply shocks to banks during the recent financial crisis and firm innovation activities. For this purpose, we combine data on German firms with information about their main banks. We exploit the exogenous variation in bank loan supply by applying the interbank market borrowing to assets ratio as an instrument for bank loan growth. Results of instrumental variable estimations show that firms indeed reduce their actual innovation activity during the financial crisis due to funding shortages if they are related to a bank with a lower loan growth. Moreover, we are able to show that firms with better banks in terms of higher bank loan growth are more likely to initiate product and process innovation as well as to reallocate human resources to innovation in the crisis period. Determining the impact on firm strategy, we find that strategic decisions to cope with the crisis are made independently of firms' access to external financing. Moreover, we find that the impact of external financing depends on the availability of internal funds. Thus, for firms with enough internal financing at hand, bank financing was less relevant for innovation than for firms which suffered from scarce financial means.

The determined effects coincide with the predictions made in the literature on the negative effect of credit constraints on innovation expenditures during economic downturns (e.g. Aghion et al. 2012). Our finding of a decline in innovation activity caused by a reduction in bank lending is consistent with the view that credit constraints lead to procyclical behavior. Additionally, our evidence adds largely to the understanding of how changes in the innovation department are made when (external) financing is scarce. As highlighted by works like Nanda & Nicholas (2014), firms tend to pursue more conservative innovation projects when they face shocks to external financing. Our study adds to these findings by showing that these changes in the innovation mode did not only occur in the Great Depression but also in the recent financial crisis, as firms only change their immediate innovation behavior but do not adopt a specific strategy to cope with the crisis. Our results are also related to the findings by Huber (2018) who estimates a patent reduction for Commerzbank-related firms. Assuming that reduced patents are the consequence of reduced innovation efforts, our estimates are well-suited to explain the estimates by Huber (2018).[32]

The result of the analysis has several policy implications. Firstly, in global economic downturns innovative firms are more likely to need support in times of hampered access to external financing. This is mainly rooted in the fact that innovation is important for growth, but also for the recovery of an economy after a crisis (Storm & Naastepad 2015). We propose subsidies as analyzed by Brautzsch et al. (2015) and Hud & Hussinger (2015). Aside of subsidizing firms, financial support for banks might be an option, but most helpful would be to establish a possibility to avoid credit crunches altogether through appropriate

[32]It has to be noted that the patent reduction could also be a strategic choice.

precautionary measures. Regulatory interventions like the Basel II and III frameworks were indeed helpful in covering the financial problems of banks in the aftermath of the financial crisis. One – perhaps until now little recognized – justification for such regulation is the securing of external financing for innovation and the continuance of the associated growth opportunities for economies.

4.7 Appendix

4.7.1 Descriptive statistics

Table 4.10: Distribution of firms over industries

Name	NACE Rev. 2.0 code	Firms	Percentage share
Mining	5-9, 19, 35	29	1.980
Food/Tobacco	10-12	50	3.413
Textiles	13-15	60	4.096
Wood/Paper	16-17	48	3.276
Chemicals	20-21	92	6.280
Plastics	22	64	4.369
Glass/Ceramics	23	47	3.208
Metals	24-25	141	9.625
Electrical equipment	26-27	210	14.334
Machinery	28	135	9.215
Retail/Automobile	29-30	58	3.959
Furniture /Toys/ Medical technology/Maintenance	31-33	125	8.532
Energy / Water	36-39	41	2.799
Media services	18, 58-60	53	3.618
IT/Telecommunications	61-63	104	7.099
Technical services/R&D services	71-72	162	11.058
Consulting/Advertising	69, 70.2, 73	46	3.140
Total		1465	100.000

Table 4.11: Distribution of firms over federal states

Name	Firms	Percentage share
Baden-Wuerttemberg	224	15.290
Bavaria	180	12.287
Berlin	52	3.549
Brandenburg	56	3.823
Bremen	20	1.365
Hamburg	23	1.570
Hesse	99	6.758
Lower Saxony	90	6.143
Mecklenburg-Vorpommern	27	1.843
North Rhine-Westphalia	237	16.177
Rhineland-Palatinate	39	2.662
Saarland	14	0.956
Saxony	194	13.242
Saxony-Anhalt	72	4.915
Schleswig-Holstein	30	2.048
Thuringia	108	7.372
Total	1465	100.000

4.7.2 Non-linear instrumental variable regressions

Reduced form regression utilizing a Probit estimation approach

Table 4.12: Probit estimations for the effect of interbank market borrowing on immediate innovation adjustments

Dependent variable	(1) Innovation Reduction	(2) Product innovation	(3) Process innovation	(4) Labor reallocation
Interbank	0.281***	−0.285**	−0.171	−0.279***
	(0.089)	(0.120)	(0.120)	(0.105)
Pseudo R-squared	0.138	0.046	0.034	0.048
Observations	1465	1465	1465	1465

The dependent variables are indicator variables concerning the changes in the firm's innovation behavior as of 2009. 'Innovation reduction' takes unit value if the firm has reduced the innovation activities due to funding shortages in 2009. 'Product innovation' marks the initiation of an additional product innovation. 'Process innovation' is similarly constructed for process innovation. 'Labor reallocation' takes unit value if the firm reallocated free human resources to the innovation department. The variable Interbank is calculated as the value of interbank borrowing to total assets of the firm's main bank as of 2006. Coefficients reflect the marginal effects of the Interbank estimate calculated at the mean of the explanatory variables. Each regression includes the following firm controls as described in Section 4.3.1: Log of Employees and its square, Log of Firm age, a dummy for being part of a firm group, the firm's credit rating and dummies for the perception (Low, Medium, High) of the reduction in sales and the reduction in profits in the crisis. Each regression includes industry and federal state fixed effects. Heteroscedasticity-consistent standard errors are reported in parentheses. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

Instrumental variable estimator for a binary dependent variable

Next, we apply the two-stage conditional maximum likelihood estimator (2SCML) as proposed by Rivers & Vuong (1988).[33] The estimation strategy is related to the usual two-step approach described in Section 4.3.[34] Firstly, we run a first-stage OLS regression of ΔCredit_Supply$_{ij}$ on all instruments (Interbank market ratio). In the second stage, we plug the residuals of the first-stage regression (4.2) into a Probit estimation of Equation (4.1). Standard errors are obtained by 200 bootstrap replications. This approach has two advantages: Firstly, we are able to assess the endogeneity of the ΔCredit_Supply$_{ij}$ variable by inspecting the significance of the coefficient of the residuals as suggested by Wooldridge (2002). Secondly, we avoid inconsistent estimates which are produced by the usual two-stage approach with a nonlinear estimator in the second stage (Terza et al. 2008).

Table 4.13: Estimation results using the 2SCML estimation approach

Dependent variable	(1) Innovation Reduction	(2) Product innovation	(3) Process innovation	(4) Labor reallocation
ΔCredit_supply	−0.431***	0.442**	0.263	0.420***
	(0.137)	(0.195)	(0.193)	(0.161)
First stage residuals	0.540***	−0.448**	−0.348*	−0.596***
	(0.162)	(0.224)	(0.207)	(0.183)
Log likelihood	-625.222	-954.545	-967.779	-810.099
Observations	1465	1465	1465	1465

The dependent variables are indicator variables concerning the changes in the firm's innovation behavior as of 2009. 'Innovation reduction' takes unit value if the firm has reduced the innovation activities due to funding shortages in 2009. 'Product innovation' marks the initiation of an additional product innovation. 'Process innovation' is similarly constructed for process innovation. 'Labor reallocation' takes unit value if the firm reallocated free human resources to the innovation department. The variable of interest, ΔCredit_supply is constructed as the change in credit supply by banks from 2008 to 2009. Coefficients reflect the marginal effects of the ΔCredit_supply coefficient calculated at the mean of the explanatory variables. Each regression includes the following firm controls as described in Section 4.3.1: Log of Employees and its square, Log of Firm age, a dummy for being part of a firm group, the firm's credit rating and dummies for the perception (Low, Medium, High) of the reduction in sales and the reduction in profits in the crisis. Each regression includes industry and federal state fixed effects separately. Bootstrapped standard errors obtained by 200 replications are reported in parentheses. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

[33] See Terza et al. (2008), Seid & Gurmu (2015) as well as Alessandrini et al. (2010) for recent applications.

[34] We also performed tests on the exogeneity of our instruments by making use of the minimum-distance IV Probit estimator by Newey (1987). The Stata module `overid` by Baum et al. (2006) allows for an overidentification test based on this estimator that reports a test statistic on the correlation of instruments and error term of the second stage. Results were roughly the same.

4.7.3 Possible endogenous matching

Table 4.14: Matching results to obtain the propensity score for the construction of the inverse probability weights

	(1)
Dependent variable	Treated bank
Log of Employees	0.557***
	(0.110)
Log of Employees squared	−0.044***
	(0.011)
Log of Firm age	−0.112**
	(0.050)
Part of firm group	0.125
	(0.086)
Low influence of sales reduction	0.035
	(0.157)
Med influence of sales reduction	0.062
	(0.167)
High influence of sales reduction	0.080
	(0.182)
Low influence of profit reduction	0.093
	(0.157)
Med influence of profit reduction	0.032
	(0.162)
High influence of profit reduction	0.011
	(0.179)
Firm rating	0.000
	(0.001)
Constant	−2.070***
	(0.485)
Log likelihood	-764.035
Observations	1465

Standard errors in parentheses. Treatment status is defined as being related to a bank in the upper quartile of the interbank distribution. Each regression includes industry times federal state fixed effects. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

Table 4.15: Mean comparison after matching – Means calculated using inverse probability weights

	Mean		Difference in mean	p-value
	Control	Treatment		
Log of Employees	3.870	3.798	−0.073	0.586
Log of Employees squared	17.470	16.901	−0.569	0.580
Log of Firm age	2.995	3.008	0.012	0.821
Part of firm group	0.449	0.437	−0.012	0.732
Low influence of profit reduction	0.188	0.186	−0.002	0.953
Med influence of profit reduction	0.235	0.236	0.000	0.988
High influence of profit reduction	0.361	0.346	−0.015	0.651
Low influence of sales reduction	0.182	0.174	−0.007	0.783
Med influence of sales reduction	0.256	0.257	0.001	0.966
High influence of sales reduction	0.340	0.317	−0.023	0.486
Firm rating	226.893	225.132	−1.760	0.562

4.7.4 Demand effects

Table 4.16: Matching results to obtain the propensity score for the construction of the inverse probability weights

Dependent variable	(1) Treated bank
Panel A: Group 1 (N=85)	
Log of Employees	0.179
	(0.123)
Firm rating	−0.002
	(0.004)
Panel B: Group 2 (N=39)	
Log of Employees	0.996***
	(0.348)
Firm rating	0.001
	(0.006)
Panel C: Group 3 (N=59)	
Log of Employees	0.042
	(0.108)
Firm rating	0.004
	(0.004)
Panel D: Group 4 (N=74)	
Log of Employees	0.138
	(0.103)
Firm rating	−0.006
	(0.004)
Panel E: Group 5 (N=56)	
Log of Employees	−0.048
	(0.180)
Firm rating	−0.023***
	(0.007)
Panel F: Group 6 (N=24)	
Log of Employees	0.228
	(0.217)
Firm rating	0.003
	(0.004)
Panel G: Group 7 (N=64)	
Log of Employees	0.459***
	(0.145)
Firm rating	0.005
	(0.005)

(*continued*)

Table 4.16: *Continued*

Dependent variable	(1) Treated bank
Panel H: Group 8 (N=66)	
Log of Employees	0.475***
	(0.141)
Firm rating	0.002
	(0.005)
Panel I: Group 9 (N=85)	
Log of Employees	0.577***
	(0.167)
Firm rating	0.007*
	(0.004)
Panel J: Group 10 (N=32)	
Log of Employees	0.559**
	(0.266)
Firm rating	0.012
	(0.009)
Panel K: Group 11 (N=73)	
Log of Employees	0.404***
	(0.123)
Firm rating	−0.001
	(0.003)
Panel L: Group 12 (N=74)	
Log of Employees	0.249*
	(0.132)
Firm rating	0.005
	(0.004)

Treatment status is defined as being related to a bank in the upper quartile of the interbank distribution. Standard errors in parentheses. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

Table 4.17: Mean comparison after matching – Means calculated using inverse probability weights

	Mean		Difference in mean	p-value
	Control	Treatment		
Panel A: Group 1 (N=85)				
Log of Employees	3.912	3.947	0.021	0.894
Firm rating	220.805	221.610	0.017	0.912
Panel B: Group 2 (N=39)				
Log of Employees	2.912	2.898	−0.014	0.963
Firm rating	253.636	242.455	−0.205	0.505
Panel C: Group 3 (N=59)				
Log of Employees	4.361	4.173	−0.074	0.718
Firm rating	231.458	233.875	0.045	0.828
Panel D: Group 4 (N=74)				
Log of Employees	4.566	4.793	0.110	0.479
Firm rating	205.738	208.500	0.057	0.712
Panel E: Group 5 (N=56)				
Log of Employees	3.387	3.196	−0.124	0.575
Firm rating	211.333	211.571	0.008	0.972
Panel F: Group 6 (N=24)				
Log of Employees	2.694	2.905	0.248	0.444
Firm rating	264.400	253.800	−0.186	0.564
Panel G: Group 7 (N=64)				
Log of Employees	3.992	3.996	0.002	0.991
Firm rating	225.625	227.167	0.032	0.876
Panel H: Group 8(N=66)				
Log of Employees	3.398	3.400	0.001	0.996
Firm rating	235.821	242.393	0.121	0.525
Panel I: Group 9 (N=85)				
Log of Employees	4.106	4.072	−0.026	0.871
Firm rating	227.526	228.579	0.019	0.908
Panel J: Group 10 (N=32)				
Log of Employees	3.847	4.116	0.171	0.499
Firm rating	231.750	220.688	−0.258	0.311
Panel K: Group 11 (N=73)				
Log of Employees	5.195	5.198	0.002	0.995
Firm rating	206.667	208.611	0.023	0.924
Panel L: Group 12 (N=74)				
Log of Employees	4.331	4.197	−0.071	0.669
Firm rating	215.162	220.865	0.080	0.628

4.7.5 Estimator for an ordered dependent variable

Table 4.18: Estimation results and marginal effects for an ordered dependent variable

	(1)	(2)	(3)	(4)	(5)
	Ordered Probit	Marginal effect			
		No impact	Low impact	Medium impact	High impact
Panel A: Product / service cost reduction					
ΔCredit_Supply	0.131	−0.014	−0.023	−0.016	0.052
	(0.426)	(0.042)	(0.075)	(0.052)	(0.169)
Panel B: Production and offer renewal					
ΔCredit_Supply	0.312	−0.070	−0.049	0.025	0.095
	(0.408)	(0.089)	(0.067)	(0.034)	(0.122)
Panel C: Extension of supply to new markets					
ΔCredit_Supply	0.703*	−0.119*	−0.112	−0.031	0.262*
	(0.424)	(0.069)	(0.070)	(0.021)	(0.157)

The dependent variables are indicator variables concerning the changes in the firm's innovation behavior as of 2009. 'Cost reduction' is a four point scale variable which indicates the impact (None, Low, Average, High) of pursuing a production/service cost reduction strategy to cope with the changing economic conditions during the crisis. 'Offer renewal' and 'Extension of supply to new markets' are constructed similarly for the questions of the impact of the renewal of existing production and service offers and the extension of supply to new market segments/ customer groups. The variable of interest, ΔCredit_Supply is constructed as the change in credit supply by banks from 2008 to 2009. Coefficients reflect the estimates for ΔCredit_Supply for each subgroup. Each regression includes the following firm controls as described in Section 4.3.1: Log of Employees and its square, Log of Firm age, a dummy for being part of a firm group, the firm's credit rating and dummies for the perception (Low, Medium, High) of the reduction in sales and the reduction in profits in the crisis. Each regression includes industry and federal state fixed effects separately. Bootstrapped standard errors obtained by 200 replications are reported in parentheses. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

Chapter 5

The sensitivity of R&D to financing constraints of firms as well as of their banks

Co-authored with Kornelius Kraft

5.1 Introduction

The social (i.e. technological progress, growth) and private (i.e. competitive advantages) incentives to invest in R&D have been known for some time (Aghion et al. 2005; Jones & Williams 1998; Solow 1957; Zachariadis 2004). Even if this is the case, financing constraints are one of the major factors leading to an underinvestment in R&D (European Commission 2010a; European Commission 2010b; Eurostat 2008; Hall & Lerner 2010). This is mainly rooted in the special characteristics of this kind of expenditure, including significant uncertainties, huge sunk costs, low collateral and a high proportion of expenditure for personnel (Hall 2002; Hall & Lerner 2010). Moreover, capital market imperfections due to adverse selection and moral hazard make R&D financing by external sources difficult (Hall 2002; Hall & Lerner 2010). These theoretical considerations of the impact of financing constraints on R&D are widely discussed (e.g. Hall 2002; Hall & Lerner 2010).

Although financing constraints for R&D have also been investigated empirically for some time (e.g. Czarnitzki & Hottenrot 2010; Hall et al. 2016; He & Tian 2018), it remains questionable whether R&D reacts sensitively to the supply of external financing in general and bank financing in particular (e.g. Hall 2002; Brown et al. 2012; Kerr & Nanda 2015). This is said to be rooted in the characteristics of R&D projects which make their financing unattractive for debt holders like banks (Hall 2002). Accordingly, it is assumed that R&D is largely financed by internal means (e.g. Bougheas et al. 2003; Knudsen & Lien 2014). However, studies find that there is an impact of bank characteristics (frequently measured as averages on the regional level) on R&D or its inputs (e.g. Benfratello et al. 2008; Hsu et al. 2014; Nanda & Nicholas 2014). Thus, the question of the relevance of bank financing for R&D remains under debate (e.g. Hall 2002; He & Tian 2018; Kerr & Nanda 2015). The aim of this paper is to contribute to this discussion by providing first evidence of how the relevance and intensity of the individual constraints of a firm to finance R&D differ as a function of the general financial market situation and the specific situation of their main bank. For this purpose, the paper analyzes two main research questions. First, what effect do fundamental changes to the situation on the financial market have on the firms' financial restrictions (in terms of relevance and intensity)? Second, to what extent does this effect depend on the constraints of their main bank as supplier of external finance?

To answer these questions, we utilize the firms' credit rating as a measure for financing constraints. Additionally, we consider the financial crisis (2008–2009) and the simultaneous introduction of the Basel II accord (2007) as periods in which the degree of financing constraints for R&D intensifies. The reason for this lies in the fact that the enactment of the Basel II accord in 2007 is accompanied by stronger regulations concerning bank capital requirements, credit risk assessment by banks and a stronger emphasis on the borrower's credit rating (e.g. Scellato & Ughetto 2010; Schindele & Szczesny 2016).[1] Additionally,

[1] See Schindele & Szczesny (2016) as well as Scellato & Ughetto (2010) for a detailed description of the Basel II guidelines.

the financial crisis of 2008/2009 marks a period of increased information asymmetries between borrower and lender (e.g. Gilchrist & Mojon 2018), stronger collateral requirements (e.g. Gilchrist & Mojon 2018) and credit supply reductions (e.g. Puri et al. 2011). Thus, both events affected banks and lead us to expect that financially constrained firms (i.e. firms with worse credit ratings) would face even more serious problems in financing their R&D expenditure between 2007 and 2009 compared to the prior period.[2] By additionally utilizing a post-crisis period (2010–2012), we have the opportunity to test whether the firm's sensitivity of R&D to financing constraints returns to its pre-crisis level.[3]

In a second step, we provide first evidence of whether the sensitivity (in terms of strength and duration) of R&D to financing constraints during the financial crisis is conditional on the firm's main bank balance sheet strength. Bank capital serves as an indicator for bank balance sheet strength and plays a particularly important role in the resilience of banks to adverse shocks and their impact on the real economy e.g. via bank lending (Diamond & Rajan 2000; Holmstrom & Tirole 1997; Jiménez et al. 2012; Kapan & Minoiu 2018). In that respect, it is empirically shown that banks with higher bank capital realize larger loan growth rates (e.g. Kapan & Minoiu 2018; Gambacorta & Shin 2018) and are subject to a lower probability of default (e.g. Berger & Bouwman 2013) in the recent financial crisis. Moreover, bank capital requirements play an important role in the Basel II accord to improve the banks' risk management (Schindele & Szczesny 2016). Consequently, it is to be expected that the effect of financial constraints for R&D in the period between 2007 and 2009 depends on the firm's main bank's degree of capitalization.

Our data basis is the Mannheim Innovation Panel (MIP), i.e. the German part of the Community Innovation survey (CIS), for the years 2002 to 2012. We combine the MIP with two additional data sets. First, we add a credit rating index calculated by Creditreform, the leading firm rating agency in Germany. Second, having information on the firm's main bank identifier allows us to merge the MIP with bank balance sheet information from Bankscope, compiled by Bureau van Dijk. Having access to this rich data set allows us to test whether firms react more sensitively to financing constraints in the financial crisis by applying a difference-in-differences estimation approach. For this objective, we utilize the firm's credit rating as a continuous treatment indicator which measures the firm's degree of financing constraints (i.e. the situation of internal financing and access to external financing).[4] This allows us to test whether there is a change in impact of the extent of a firm's financial constraints on R&D from the pre-crisis period (2002–2006) to the financial crisis (2008–2009) and the simultaneous introduction of the

[2] See e.g. Lee et al. (2015) who show that financing problems of firms became more severe in the recent financial crisis. Also Kulicke et al. (2010) and Rammer (2011) show that R&D of German companies decreased in the recent financial crisis.

[3] See e.g. Giebel & Kraft (2019) as well as Hud & Hussinger (2015) who also consider 2010 as a post-crisis year in the context of R&D financing. Our approach, however, extends this post-crisis time-period even further.

[4] See e.g. Czarnitzki (2006), Czarnitzki & Hottenrott (2011a), Czarnitzki & Hottenrott (2011b), Czarnitzki & Kraft (2007) as well as Peters et al. (2017) for applications.

Basel II accord (2007). Utilizing a post-crisis period (2010-2012) gives us the opportunity to test whether the effect is persistent in the period after the financial crisis or returns to its pre-crisis level. Taking advantage of the information on the firm's main bank, we measure for its capitalization to classify the banks as low or high-capitalized banks. This allows us to subsequently apply difference-in-differences regressions for firms related to high and low-capitalized banks.

The difference-in-differences results with two treatment periods indicate that the sensitivity of R&D to financing constraints is stronger during the financial crisis than the period before. Thus, firms with higher constraints reduced their R&D spending more strongly than firms with lower constraints during the main crisis period. Making use of the bank's capital endowment and applying difference-in-differences regressions for firms related to high and low-capitalized banks leads to the following results: The intensity of financing constraints for R&D in times of stress on financial markets and the enactment of the Basel II accord depends on the firm's main bank characteristics. In other words, firms related to banks with less capital resources suffered particularly in the crisis period. Consequently, the greater impact of financing constraints on R&D during the crisis is driven by the financial crisis and only partly – if at all – by the implemented Basel II guidelines. Corporate customers of banks with better capitalization show no significantly different behavior with respect to R&D expenditures when the pre-crisis and the post-crisis periods are compared to the crisis period. The validity of these results is underlined by various robustness tests (e.g. scaling the dependent variable, alternative modelling choices, changes to the rating variable, adjustments to the bank measures, changes to sample size and time period redefinitions). Moreover, accounting for a possible endogenous matching between firms and banks as well as sample selection does not alter the results considerably.

We extend these considerations by analyzing the effect of subsidies, which are an important financing source for R&D (e.g. Almus & Czarnitzki 2003; Becker 2015; Howell 2017). As this holds especially in the recent financial crisis (e.g. Brautzsch et al. 2015; Hud & Hussinger 2015), we utilize information on subsidies for innovation and perform additional tests. First, we control for the effect of subsidies in our main regression approach. We show that firms which received a subsidy during the financial crisis show higher R&D spending than non-recipients compared to the period before. The impact of firm financing constraints on R&D remains unchanged when we control for the receipt of subsidies. Second, we test whether the impact of financing constraints for R&D differs according to receipt of subsides. Results of these tests imply that firms which are classified as subsidy recipients show no increased sensitivity to financing constraints in the financial crisis. Those who do not receive a subsidy have greater problems in financing their R&D expenditures during the crisis period. We extend these considerations by also taking into account bank financing constraints in a third step. We find that firms which are categorized as subsidy recipients show no greater sensitivity to firm financing constraints during

the financial crisis, even if the firm is related to a low-capitalized bank. Thus, our results indicate that subsidies can mitigate financing constraints of firms.

The results of the study contribute to the literature in several ways. First, we extend the strand of literature investigating the effect of financial constraints (i.e. cash flow) on R&D (e.g. Harhoff 1998; Hall et al. 2016; Himmelberg & Petersen 1994) and literature that uses a credit rating index as indicator for financing constraints to explain R&D expenses (e.g. Czarnitzki 2006; Czarnitzki & Hottenrott 2011a; Czarnitzki & Hottenrott 2011b; Peters et al. 2017). We add to both strands of literature by investigating whether the effect of financial constraints on R&D is stronger in times of stress on financial markets or when banks scrutinize the credit worthiness of their borrowers more closely. In that respect, our study largely extends the above-mentioned literature by additionally considering potential changes in the supply of external financing. Thus, we add novel evidence to this strand of literature by investigating the heterogeneity of this effect when exploiting information on the supplier of external financing – the firm's main bank. For this reason, we also contribute to and extend the strand of literature investigating the effect of financing constraints on R&D spending in dependence of restricted supply of external (equity) financing (e.g. Brown et al. 2009; Brown et al. 2012; Brown et al. 2013; Brown & Petersen 2009; Brown & Petersen 2011). This is mainly due to the fact that we, in contrast to these studies, concentrate on restricted bank financing and use the financial crisis as a period of stress on financial markets.

Secondly, we extend work that utilizes bank characteristics to determine the effect of bank financing on firm innovation (Amore et al. 2013; Benfratello et al. 2008; Chava et al. 2013; Cornaggia et al. 2015; Hsu et al. 2014; Nanda & Nicholas 2014). We begin by addressing the effect of firm financing constraints in combination with bank financing constraints. Then, by applying firm-bank level data, we are able to draw a more detailed picture than the above-mentioned studies, which use regional indicators to identify bank characteristics. Finally, we also add to those studies which use patents as identifiers for innovation activities (e.g. Amore et al. 2013; Chava et al. 2013; Cornaggia et al. 2015; Nanda & Nicholas 2014) by considering R&D expenditures. This allows us to overcome issues related to the use of patents as a dependent variable (He & Tian 2018). Moreover, using R&D opens up the possibility to determine the direct effects of a negative shock to banks on innovation inputs.

Thirdly, we complement and extend studies which investigate the impact of firm financing on R&D in the recent financial crisis (e.g. Hud & Hussinger 2015). In that context we also add to studies which investigate the impact of firm characteristics on innovation during the crisis (e.g. Archibugi et al. 2013a; Archibugi et al. 2013b; Campello et al. 2010; Filippetti & Archibugi 2011; Paunov 2012). We do so by considering financial constraints of firms and bank characteristics to identify constraints from the supply side. Additionally, we extend these studies significantly by considering the changing impact of financing

constraints over time. Moreover, utilizing a period after the financial crisis is informative since it otherwise remains unclear whether the original situation returns. This third period is not usually considered by other studies (e.g. Archibugi et al. 2013a; Archibugi et al. 2013b; Campello et al. 2010; Filippetti & Archibugi 2011; Paunov 2012) or extends the post-crisis period already used (e.g. Hud & Hussinger 2015).

Fourthly, we contribute to the strand of literature that utilizes a matched firm-bank data set to determine the effects of changes in credit supply on German firms during the recent financial crisis (e.g. Dwenger et al. 2018, Giebel & Kraft 2019; Huber 2018). We extend Dwenger et al. (2018) and complement Giebel & Kraft (2019) as well as Huber (2018) by analyzing the impact of the changing conditions on financial markets and a restrictive supply of external financing on the sensitivity of R&D to firm financing constraints. In contrast to Giebel & Kraft (2019) as well as Huber (2018), we apply a credit rating index as proxy for internal finance and determine its changing impact over time. Unlike these two studies, we utilize bank capital to identify bank credit supply restrictions and their impact on R&D. Thus, especially in contrast to Huber (2018), we consider R&D expenses as innovation input while Huber (2018) uses patents as an innovation output measure. We also extend Giebel & Kraft (2019) by adding a period after the financial crisis to determine whether the impact of financing constraints remains enhanced or whether it declines to the pre-crisis level. Utilizing a matched firm-bank data set, we also extend studies which investigate the impact of banks' capital resources on banking during the financial crisis (e.g. Beltratti & Stulz 2012; di Patti & Sette 2016; Gambacorta & Shin 2018; Kapan & Minoiu 2018; Košak et al. 2015) by adding evidence for the effects on the real economy, namely R&D expenditures of firms. Moreover, analyzing the effect of financing constraints on R&D by utilizing a credit rating index and bank capital indicators, we contribute to and extend studies which investigate the impact of the Basel II reform on firms (e.g. Schindele & Szczesny 2016; Scellato & Ughetto 2010).

Taking up subsidies as an additional financing source of firms, we contribute to the literature that investigates the impact of subsidies on R&D in general (e.g. Howell 2017) and the literature on the effect of subsidies on R&D in the recent financial crisis in particular (e.g. Aristei et al. 2017; Brautzsch et al. 2015; Hud & Hussinger 2015). We add to the literature on the impact of subsidies in the financial crisis by showing that subsidies affect R&D positively in times of stress on financial markets. Our consideration of bank and firm financing constraints add to the studies mentioned before, as we can show that financing constraints could be mitigated by R&D subsidies. Due to this feature of our work, we also contribute significantly to branches of literature which show that R&D subsidies are important for financially constrained firms (e.g. Howell 2017), mitigate financing constraints in general (e.g. Takalo & Tanayama 2010) and affect the extent of financing constraints for R&D (e.g. Hyytinen & Toivanen 2005).

Our paper proceeds as follows: Section 5.2 focuses on financing constraints and the impact of distress in the financial system on firm financing and R&D. Data, variables and methodology are explained in Section 5.3. The regression results are covered in Section 5.4. Section 5.5 covers the description and results of several robustness tests. The last Section 5.6 of Chapter 5 presents the concluding remarks.

5.2 Financing constraints and R&D expenses in an economic downturn

5.2.1 The impact of restrictions to internal financing

According to the pecking order of financing, (e.g. Hubbard 1998; Myers & Majluf 1984), firms prefer internal means (e.g. cash flow) over external sources (e.g. bank loans) and equity to finance investments. As financial preferences for firms vary, firms likewise engage in a funding mixture of the aforementioned financing instruments (Beck et al. 2008). In case of a perfect capital market, obtaining the necessary amount of external funding to finance any type of investment might be no problem (Modigliani & Miller 1958). However, imperfections on capital markets exist that are rooted in agency conflicts and asymmetric information problems (Holmstrom & Tirole 1997; Stiglitz & Weiss 1981). These issues lead to higher costs for external funding and difficulties in switching between financing sources (Holmstrom & Tirole 1997; Stiglitz & Weiss 1981). Thus, in imperfect capital markets, a difference in the costs between internal and external funds exists (Fazzari et al. 1988).

R&D investments are particularly subject to this type of problem as they are usually sunk, provide low collateral and are connected with uncertainties (Hall 2002). The latter point refers to the fact that the future success of the innovation process and the prospective market acceptance are not known to the firm (Hall 2002). Moreover, asymmetric information between borrower and lender prevail (Hall 2002). These are likewise severe as the borrower might not want to provide a valuable signal about the value of the R&D project (Bhattacharya & Ritter 1983) although a patent could serve as a quality signal (Hottenrott et al. 2016; Hochberg et al. 2018).

The relation between R&D expenditures and cost of capital is shown in Figure 5.1.[5] As increasing costs of capital make R&D expenses less attractive, the demand for R&D investment is depicted by the downward sloping marginal rate of return curve D. Its location is determined by the future profits of the R&D investment. The marginal cost of capital curve depicts the supply of capital and consists of two parts. The horizontal part represents the constant marginal costs of capital for internal funds. The amount of

[5]The graphic representation follows works like David et al. (2000); Hall (2002); Hottenrott & Peters (2012); Knudsen & Lien (2014).

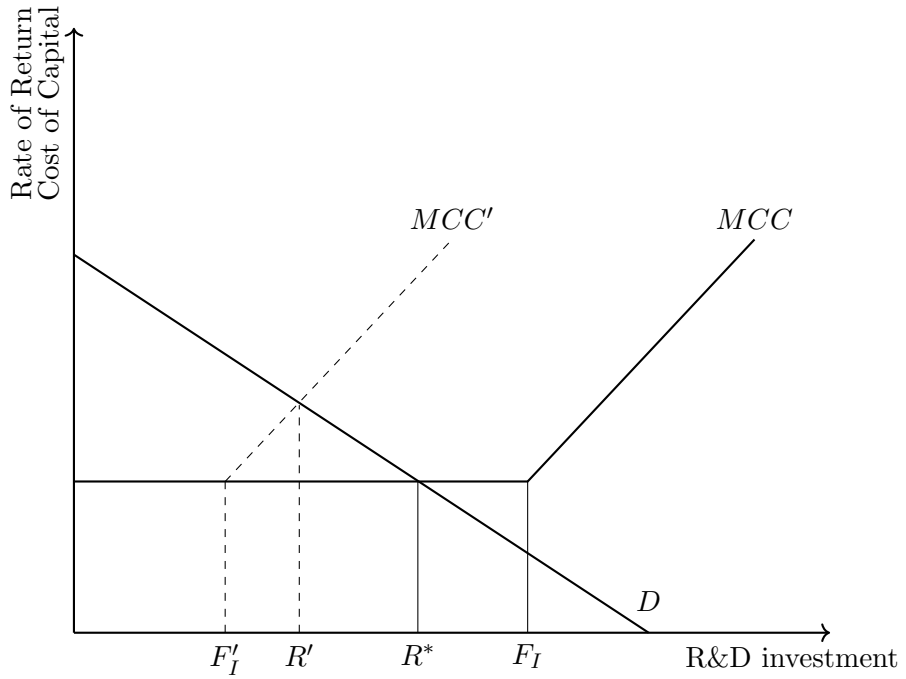
available internal means is denoted by (F_I) and external capital costs are depicted by the steeper part of the MCC-curve. The upward slope results from the increased costs of capital for this type of funds as argued above. Due to the characteristics of innovation highlighted above, it is argued that this type of investment is largely financed by internal means (e.g. Carpenter & Petersen 2002; Hall & Lerner 2010; Fazzari et al. 1988; Ughetto 2008). Thus, we assume that the intersection between the demand and costs of capital curves lies in the horizontal area of internal financing. This intersection point marks the optimal amount of R&D investment (R^*) for the firm.

In an economic downturn like the recent financial crisis, consumer demand falls (OECD 2009; Storm & Naastepad 2015). The resulting reduction in output decreases the opportunity costs of reallocating resources from manufacturing to R&D. Due to this opportunity cost effect, firms would rather invest counter-cyclically in R&D (Aghion & Saint-Paul 1998; Barlevy 2007). On the other hand, it is also argued that the decrease in demand might lead to reduced R&D spending, due to lower investment incentives (Schmookler 1966; Shleifer 1986). Thus, it is questionable whether the opportunity cost effect exerts any impact on R&D expenses. Following the argumentation of Knudsen & Lien (2014) the R&D-enhancing opportunity cost effect only predominates when the fall in demand is small. When the fall in demand is large enough, internal means decrease and the need for funding from external sources increases. In this case the opportunity cost effect is dominated by the consequences resulting from reductions in internal means and credit supply (Aghion et al. 2012; Knudsen & Lien 2014; López-Garcia et al. 2013).

Figure 5.1 depicts the change in investment levels when a negative shock to internal financing occurs while external financing costs remain the same. The new costs of capital curve MCC' consists of a shorter horizontal part, ending at the point with the maximum available internal financing F_I'. The firm experiencing a negative shock to internal financing realizes investment amount R' which is lower than the optimal amount of investment R^*. Consequently, the contraction of internal financing from F_I to F_I' leads to an investment reduction from R^* to R'.[6] Empirical studies on financing constraints show that lower internal means are indeed associated with lower R&D spending (e.g. Czarnitzki & Hottenrott 2011a; Czarnitzki & Hottenrott 2011b; Hall 1992; Harhoff 1998; Himmelberg & Petersen 1994; Peters et al. 2017).

[6] Alternatively, we could think about a continuum of firms with the same demand curve and the same difference between internal and external costs of financing. However, the firms differ with respect to internal means available such that the range of internal financing lies between F_I' and F_I. The resulting R&D expenditures would range from R' to R^*.

Figure 5.1: The optimal R&D investment with and without internal financing constraints



Notes: The figure shows the relationship between demand for financials resources to cover R&D expenditures and the supply of capital. Demand is reflected by the marginal rate of return curve (D) while supply is indicated by the marginal cost of capital curve (MCC). The available internal financing is denoted by F and lies at the end of the constant part of the MCC curve. The intersection between supply and demand determines R which is the amount of investment made.

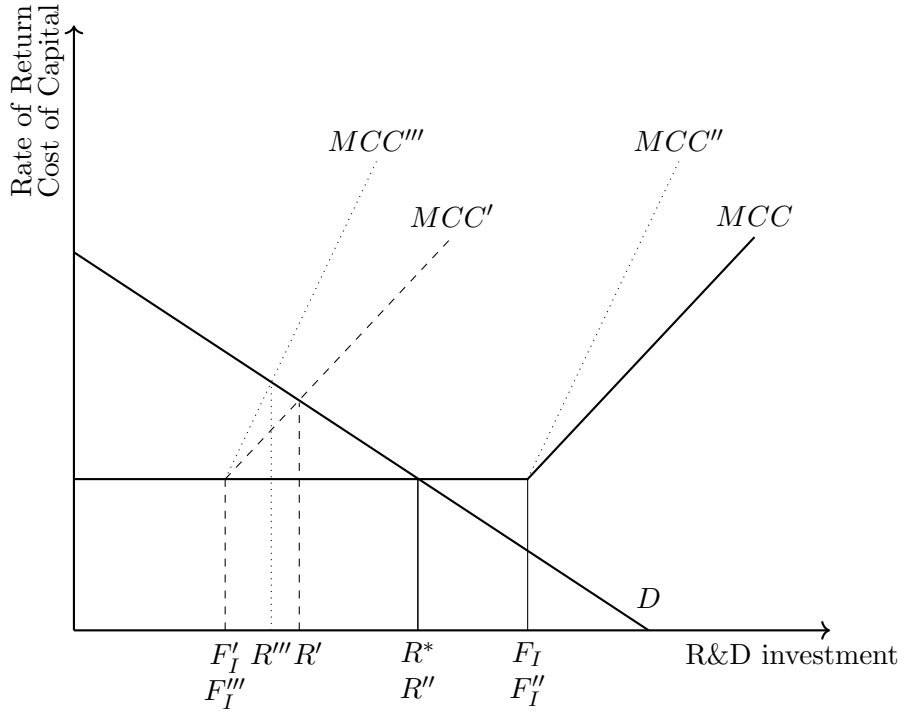
5.2.2 The impact of external financing supply

In an economic downturn the supply of external financing also declines (Jiménez et al. 2012), another feature observed during the recent financial crisis (Bundesbank 2009; Holton et al. 2014; Kapan & Minoiu 2018). Enhanced costs for external funding, for example due to a shock on financial markets, led to an inward shift of the upward sloping part of the MCC curve. This situation, assuming a shift in this part of the MCC curves for all firms, is depicted in Figure 5.2. A reduction in external financing is not binding if enough internal finance is available. This situation is illustrated by the rotation of the upward sloping part of MCC to MCC''.[7] However, if the firm faces a negative shock to internal financing and has higher external capital costs (i.e. due to a negative shock), the new cost of capital curve is denoted by MCC'''. The resulting optimal investment under these conditions is R'''. This point is further reduced than in the absence of a reduced supply of external finance, when MCC' would be relevant and R' would be realized. Accordingly, R''' is also below the initial, optimal investment volume (R^*). Thus, besides the availability of internal means, access to external finance plays a crucial role with respect to R&D financing (Hall 2002; Hall & Lerner 2010). Within the financial constraints liter-

[7]The underlying assumption is that the firm does not reallocate capital away from investment R if the external capital costs increase to finance any other investment.

ature, studies indeed find a higher R&D to cash flow sensitivity when controlling for the use of external finance by equity (e.g. Brown et al. 2012).

Figure 5.2: The optimal R&D investment under internal and external financing constraints



Notes: The figure shows the relationship between demand for financial resources to cover R&D expenditures and the supply of capital if external financing constraints are taken into account. Demand is reflected by the marginal rate of return curve (D) while supply is indicated by the marginal cost of capital curve (MCC). The available internal financing is denoted by F and lies at the end of the constant part of the MCC curve. The intersection between supply and demand determines R which is the amount of investment made.

Especially in bank-based systems like Germany, banks are the main supplier of external finance (Audretsch & Elston 1997; Edwards & Fischer 1996; Elsas & Krahnen 1998; De Massis et al. 2018) and firm financing depends largely on bank loan supply (e.g. Agarwal & Elston 2001; Berger & Udell 1995; Chava & Purnanandam 2011; Kahle & Stulz 2013). It is shown that financially distressed firms face problems in accessing external financing in normal times (e.g. Harhoff & Körting 1998). Thus, a negative bank shock might affect firm financing in the form of higher borrowing costs and lower credit supply (e.g. Upper & Worms 2004). This also holds for the recent financial crisis, a period in which firms faced increased costs for – and reduced supply of – external financing in terms of bank credit (e.g. Bundesbank 2009; Puri et al. 2011).[8]

During the crisis the banks individually experienced varying degrees of problems due to the different amounts of equity or other reserves that strengthened their capital base (Adrian et al. 2018; Beltratti & Stulz 2012; Berger & Bouwman 2013; Jiménez et al.

[8]See Section 5.4.3 for an explanation of the impact of subsidies on firm financing and the extent of financing constraints. Moreover, Section 5.4.3 covers the respective empirical tests.

2012; Kapan & Minoiu 2018). Bank capital reflects a bank's own funds (Adrian et al. 2018), determines its ability to absorb losses (Diamond & Rajan 2000; Kapan & Minoiu 2018; Mingo 1975), serves as proxy for the agency costs of borrowing (Holmstrom & Tirole 1997; Jiménez et al. 2012) and determines the costs of funding i.e. lending on the interbank market (Adrian et al. 2018; Gambacorta & Shin 2018; Kapan & Minoiu 2018; Mingo 1975). Thus, higher bank capital is associated with higher bank lending in general (e.g. Berrospide & Edge 2010; Buch & Prieto 2014). Additionally, bank capital matters for the transmission of financial shocks to lending (Gambacorta & Mistrulli 2004; Peek & Rosengren 1997).[9] This is also observed in the recent financial crisis, as studies (e.g. Beltratti & Stulz 2012; di Patti & Sette 2016; Gambacorta & Shin 2018; Kapan & Minoiu 2018; Košak et al. 2015) show that the contraction of lending by banks indeed depended on bank capitalization. Moreover, the enactment of the Basel II accord in 2007 was connected with minimum capital requirements for banks (e.g. Schindele & Szczesny 2016). These were intended to induce banks to make provisions for risks (e.g. Schindele & Szczesny 2016). Consequently, we expect that firms with higher financing constraints which are associated with a poorly capitalized bank would reduce their R&D expenditures to a greater extent than firms with lower financing constraints during the financial crisis. For firms associated with a more strongly capitalized bank, we assume that the sensitivity of R&D to financing constraints would not change remarkably during the crisis.

5.3 Data and methodology

5.3.1 Data and Variables

We use data for the years 2002 to 2012 from the Mannheim Innovation Panel (MIP). The MIP is the German part of the Community Innovation Survey (CIS).[10] It comprises data for firm-specific information concerning R&D-like innovation and R&D expenses on a yearly basis. Each firm in our sample has bank account information. Consequently, we are able to combine the basis MIP data with bank balance sheet data from Bankscope which is compiled by Bureau van Dijk. By combining both data sets we are able to construct a yearly data set with repeated cross sections, since not all firms answer the questionnaire regularly. The firms in our sample stem from the high-tech and low-tech manufacturing sectors as well as knowledge intensive services. These are roughly all industries sampled in the MIP and comprise the NACE Rev 2.0 codes from 5 to 39 and 58 to 66 as well as 69 to 73. Our final sample consists of 8,739 firm-years for 3,252 firms.

[9] See e.g. Kleff & Weber (2008) as well as Memmel & Raupach (2010) for analysis concerning bank capital in Germany.

[10] See Aschhoff et al. (2013) for more methodological details of the MIP for the survey waves 2006 to 2010.

To test for the impact of financing constraints on R&D, we utilize the R&D expenditures of firms, as commonly applied in the literature (e.g. Brown et al. 2012; Czarnitzki & Hottenrott 2011b). To improve the distribution properties of the dependent variable, we use the logarithm of R&D expenses. Since some firms possibly perform no R&D and have no related expenses, we observe zero values. Simply applying the logarithm would lead to the drop of these zero value observations, which would result in a serious bias in our results. Thus, we apply the transformation ln(R&D+1).[11]

As identifier of firms' financing constraints, we apply the firm's individual credit rating 'Rating' in accordance with the suggestion of Carreira & Silva (2010). The utilized rating index is calculated by the largest German credit rating agency, Creditreform. It is constructed utilizing several qualitative and quantitative factors and ranges from 100 (best rating) to 600 (worst rating). The construction of the rating index allows a characterization of the financial situation of a firm.[12] In that respect, Czarnitzki (2006), Czarnitzki & Hottenrott (2011a), Czarnitzki & Hottenrott (2011b) used the credit rating as a measure for access to external capital and for the internal financing situation of the firm[13], and Peters et al. (2017) applied it as indicator for the financial strength of a firm.[14] Our sample does not include firms with pre-crisis rating values larger or equal to 500 as these firms are close to bankruptcy.

Additionally, we use variables for firm characteristics that are common to the literature: Lagged employees in thousands 'Size' and its square 'Size squared' as well as firm age in years 'Age' and its square 'Age squared'. 'Group membership' is a dummy variable indicating whether the unit belongs to a firm group (unit value) or not (zero). Additionally, we use the lagged share of exports divided by sales 'Export share' to control for demand-related influences on the R&D expenditures.[15] Moreover, we utilize the lagged value of sales growth 'Sales growth' as an additional indicator for the financial situation of the firm.

Next, we use our bank balance sheet information from the Bankscope database to apply several measures as proxy for the bank's financial strength in terms of capital. For reasons of exogeneity, all variables are measured as of 2006 such that they are determined prior to the crisis[16] and before the Basel II guidelines became binding. One variable used is the

[11] Similar results are achieved if we apply the logarithm according to Cameron & Trivedi (2010) and use γ, a slightly smaller value than the minimum value as censoring point.

[12] The index is built from several firm information like liquidity, balance sheet structure, financing, legal form, ownership structure, industry, prior credit requests, ability to repay credits in time. See e.g. Czarnitzki & Hottenrott (2011a) for a detailed description of the construction of the rating index. We include federal state fixed effects to control for the possible regional variation in the index.

[13] Czarnitzki & Kraft (2007) show that a weaker firm rating is indeed correlated with higher interest rate payments.

[14] Moreover, we use the lagged rating 'Lagged Rating' value to verify the robustness of our results.

[15] See e.g. Bricongne et al. (2012) and Eaton et al. (2016) who show that the fall in demand during the financial crisis is correlated with exporting activity.

[16] See e.g. Beltratti & Stulz (2012) for a similar handling of variables.

ratio of equity to total assets, which corresponds to the inverse leverage ratio (Adrian et al. 2018; Berger & Bouwman 2013; Jiménez et al. 2012). However, we follow the literature (e.g. Anginer et al. 2016; Bayazitova & Shivdasani 2012; Bitar et al. 2018; Demirguc-Kunt et al. 2013; Kapan & Minoiu 2018, Tran et al. 2016) and take into account the quality of capital by using tangible common equity which does not include intangible assets, goodwill and preferred stock (Bayazitova & Shivdasani 2012; Kapan & Minoiu 2018). Thus, we utilize the ratio of tangible common equity over tangible assets to create the variable 'Tangible common equity'.[17] A higher ratio implies a higher share of high-quality capital and therefore a better ability to absorb losses and to withstand shocks (Kapan & Minoiu 2018). Furthermore, investors prefer this ratio over regulatory ratios like the Tier 1 ratio (Kapan & Minoiu 2018).

We then apply the 'Capital funds' measure which is determined by the ratio of capital funds to total assets (Avdjiev et al. 2019; Nguyen 2012). Capital funds include equity, hybrid capital and subordinated debts (Avdjiev et al. 2019). Both subordinated debt and hybrid capital belong to Tier 2 capital (e.g. Brinkmann & Horvitz 1995; Demirguc-Kunt et al. 2013; Ito & Sasaki 2002; Llorens & Martin-Oliver 2017; Montgomery 2005) and have the ability to absorb losses (e.g. Llorens & Martin-Oliver 2017). Moreover, subordinated debt could be issued to increase the capital adequacy of banks (Ito & Sasaki 2002; Montgomery 2005). Thus, the ratio of capital funds to total assets is also used to proxy for the capital adequacy of banks (Avdjiev et al. 2019; Nguyen 2012). In additional robustness tests, we consider two further measures: first, the inverse of leverage calculated as equity over total assets 'Equity over total assets'; then, we employ the ratio of capital funds over net loans 'Capital funds over net loans'.

To determine the role of subsidies, we have access to information as to whether the firm received public financial support for innovation projects in the last three years. Answering this question, the firm could indicate whether it received funding from (i) federal states, (ii) national government, (iii) the European Union or (iv) other sources.[18] This question is covered in the years 2003 and 2004 as well as every second year from 2005 to 2013. We construct an indicator variable 'Subsidy' from this information which takes unit value if the firm received public support for innovation projects from any of the aforementioned sources in the current year.

Descriptive statistics are shown in Table 5.1.[19] In about 25 percent of cases R&D expenses are equal to zero. Firm size is 344 employees on average, which is above the threshold normally assumed for a small and medium size enterprise of 250 employees.

[17] The ratio of tangible common equity over risk weight assets is a commonly applied ratio in the context of the Basel III requirements on bank capital (e.g. Yan et al. 2012).

[18] The question for the survey wave in 2009 reads as follows: "Did your enterprise receive public financial support for innovation projects during 2006-2008?". The possible responses are "From states (state government departments)", "From national government (federal departments)", "From the European Union", "From others, namely:".

[19] See Table 5.6 and 5.7 in Appendix 5.7.1 for the distribution of firms over industries and federal states.

Nevertheless, more than 75% percent of the firms in our sample are SMEs. The average age of firms is about 31 years. The average credit rating is about 217 in our sample, which corresponds to a good rating according to the Creditreform index. The tangible common equity ratio amounts to a mean of about 4 percent. The size of capital funds is on average about 6% of bank assets.

Table 5.1: Descriptive statistics for 8739 firm-years

	Mean	SD	P10	P25	Median	P75	P90
Firm variables							
Log of R&D	9.676	5.816	0	7.579	11.961	13.570	17.952
Size	0.344	2.050	0.004	0.021	0.058	0.178	4.043
Age	30.67	31.323	3	12	18	35	146
Group membership	0.493	0.500	0	0	0	1	1
Sales growth	0.064	0.258	−0.540	−0.053	0.044	0.150	1
Export share	0.242	0.264	0	0.003	0.140	0.423	0.922
Rating index as of 2006	216.756	41.552	116	193	215	243	314
Lagged rating index	215.121	42.594	115	192	213	237	325
Subsidy	0.383	0.486	0	0	0	1	1
Bank variables							
Tangible common equity	4.005	2.137	1.710	2.800	4.060	5.300	9.190
Capital funds	5.768	2.303	2.700	5.150	5.380	7.140	13.710
Equity over total assets	4.088	2.102	1.750	2.920	4.150	5.310	9.190
Capital funds over net loans	13.341	9.843	6.890	8.180	11.660	15.950	41.410

Note: The count for the Subsidy variable is 6148 as this information was not available in each survey year.

5.3.2 Identification of the effect of financing constraints on R&D

First, we want to investigate the sensitivity of R&D to financing constraints in a period of stress on financial markets (financial crisis) compared to times when market conditions are more stable. For this purpose, we analyze specific time periods before (2002-2006), during (2007-2009) and after (2010-2012) the financial crisis and perform tests applying difference-in-differences estimations. Accordingly, we establish a causal relationship between the change in R&D expenditures due to the crisis and financing constraints. The intention is to test whether firms with a high financial strength change their R&D expenditures during the crisis to a lesser extent than firms with a lower financial strength.

To perform our analysis, we use the rating measure described above as of 2006 as continuous treatment indicator.[20] Additionally, we construct several indicator variables that represent specific time periods during and after the crisis. The constructed dummy 'Crisis' covers the time period of considerable tensions on financial markets and therefore

[20]We take the measure as of 2006 such that our indicator is not affected by the financial crisis in 2008/2009 or the implementation of the Basel II guidelines in 2007. Another reason for fixing the measure in 2006 is that the Basel II guidelines took effect in 2007. These guidelines promote a stronger focus on credit risk. The borrower risk is evaluated either with an internal rating-based approach or an external credit rating.

takes the value one for the years 2007 to 2009 and otherwise zero.[21] The dummy variable 'PostCrisis' comprises the time after the severe distress on financial markets and takes value one for the years 2010 to 2012 and zero for the period before (2002-2009). Accordingly, we apply the following specification with multiple treatment periods, based on Imbens & Wooldridge (2009):

$$\ln(\text{R\&D})_{it} = \beta_0 + \beta_1 \text{Rating} + \beta_2 \text{Rating}_i \times \text{Crisis}_t + \beta_3 \text{Rating}_i \times \text{PostCrisis}_t + \beta X' + \phi_i + \eta_i + \gamma_t + \varepsilon_{it} \quad (5.1)$$

Interacting 'Crisis' and 'PostCrisis' with the rating measure yields the change in R&D expenses conditional on the degree of financing constraints in the respective period compared to the period before 2007. The vector X' consists of additional control variables described above. In addition, we apply industry (ϕ), federal state (η) and year fixed effects (γ) in each regression.

As a relevant fraction of the dependent variable has zero values, we account for possible corner solutions by applying a Tobit model (Wooldridge 2010). Wald tests concerning the homoscedasticity assumption of the Tobit model led to a rejection of the homoscedasticity assumption. To cope with this problem, we use the heteroscedastic Tobit according to Greene (2003). As a result, the normal variance component σ is replaced by a functional form $\sigma_i = \sigma \times exp(Z'\alpha)$ which is obtained by inserting a set of size, age and industry dummies.

Second our analysis sheds light on the question how the supply side of external financing affects the impact of financing constraints in the financial crisis. Thus, we assume that the firm's sensitivity to financing constraints during and after the financial crisis depends on its main bank, as this is usually the most important source of external finance. We determine the level to which the bank is affected by the financial crisis if the capital endowment of the bank is in the lower quartile of the bank distribution of all German banks observed in the Bankscope database for the related bank variable.[22] This implies a ratio of tangible common equity of below 5.17 percent and a ratio of capital funds to total assets of below 5.97 percent. Thus, in a second step, we estimate Equation (5.1) separately for firms related to low and high capitalized banks.

[21] First effects of the financial crisis for the banking sector were evident in Germany in the third quarter of 2007 (e.g. Dietrich & Vollmer 2012; Puri et al. 2011). Additionally, Basel II took effect in 2007 and affected firms (credit rating) and banks (capital requirements). Robustness tests concerning the definition of the time periods are shown in Section 5.5.5.

[22] This allows us to infer from the distribution of all banks (1452) for which information is available from the Bankscope data set. Our sample covers 659 of these banks. The distribution of values for both bank capital measures are shown in Appendix 5.7.1, Figures 5.5 and 5.6.

5.4 Results

5.4.1 Sensitivity of R&D to financing constraints over time

Results of the estimations of Equation (5.1) are shown in Table 5.2. Column (1) shows the results with discarded interaction terms. The coefficient of the rating variable is negative and highly significant at the one percent level. This indicates that firms with higher financing constraints (a poor rating value) invest less in R&D than their peers with greater financial strength.

Next, we analyze whether the sensitivity of R&D to the rating variable changes over time. We include a variable for the pre-crisis, crisis and post-crisis period interacted with the rating variable. It becomes evident that the rating exerts its highest influence in the crisis period from 2007 to 2009 (Column 2). This coincides with the idea that R&D expenditures react more sensitively to financing constraints in times of distress on financial markets. For the post crisis period, it is evident that the impact of constraints on R&D almost returns to the previous level (Column 2). With respect to the time-related differences of the impact of constraints, we find that the more highly constrained firms indeed invest less in R&D in times of financial crisis (Column 3). However, we do not find a significant difference between the post-crisis and pre-crisis period (Column 3). Thus, for the estimate in Column (6), we find that a rating one point weaker coincides with a reduction in R&D expenditures by about 0.9 percentage points compared to a firm with a rating value that is one point better. At the extensive margin the results show that a firm with a rating one point weaker is 0.03 percent less likely to report a non-zero value for R&D expenditures compared to a firm with a rating that is one point better (Column 9).

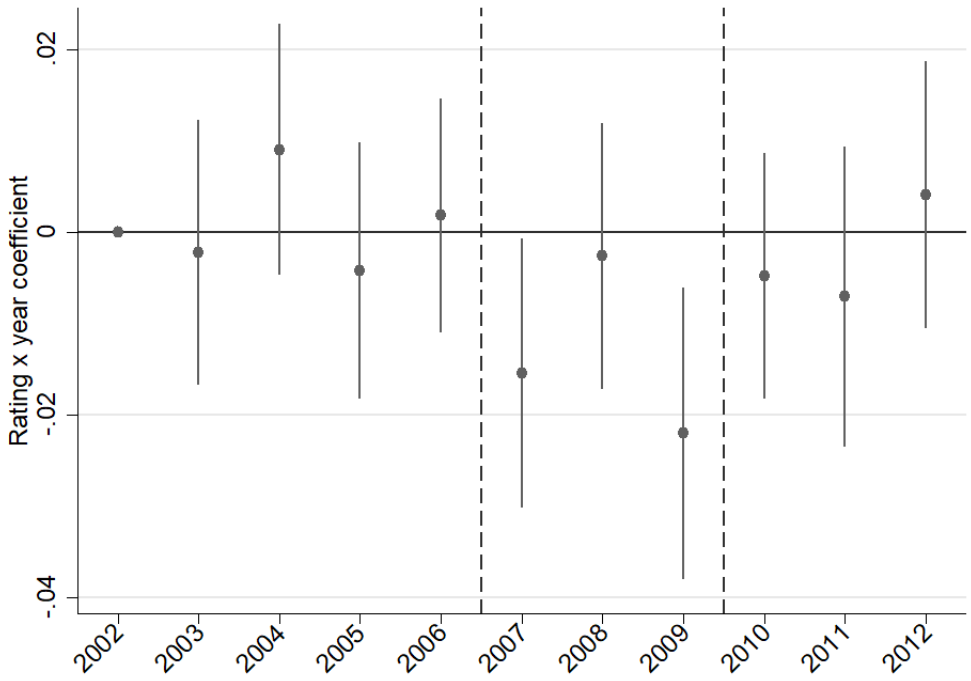
Table 5.2: Impact of firm financing constraints on R&D over time

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Tobit	Margin		Tobit	Margin		Tobit	Margin	
	Tobit	Intensive	Extensive	Tobit	Intensive	Extensive	Tobit	Intensive	Extensive
Rating	−0.016***	−0.012***	−0.000***				−0.011***	−0.008***	−0.000***
	(0.003)	(0.002)	(0.000)				(0.003)	(0.003)	(0.000)
Rating × PreCrisis				−0.011***	−0.008***	−0.000***			
				(0.003)	(0.003)	(0.000)			
Rating × Crisis				−0.024***	−0.018***	−0.001***	−0.013***	−0.009***	−0.0003***
				(0.004)	(0.003)	(0.000)	(0.004)	(0.003)	(0.000)
Rating × PostCrisis				−0.016***	−0.011***	−0.000***	−0.004	−0.003	−0.000
				(0.004)	(0.003)	(0.000)	(0.004)	(0.003)	(0.000)
Size	0.896***	0.648***	0.020***	0.884***	0.640***	0.020***	0.884***	0.640***	0.020***
	(0.112)	(0.081)	(0.003)	(0.113)	(0.081)	(0.003)	(0.113)	(0.081)	(0.003)
Size squared	−0.017***	−0.012***	−0.000***	−0.016***	−0.012***	−0.000***	−0.016***	−0.012***	−0.000***
	(0.003)	(0.002)	(0.000)	(0.003)	(0.002)	(0.000)	(0.003)	(0.002)	(0.000)
Age	−0.033***	−0.024***	−0.001***	−0.034***	−0.024***	−0.001***	−0.034***	−0.024***	−0.001***
	(0.013)	(0.009)	(0.000)	(0.013)	(0.009)	(0.000)	(0.013)	(0.009)	(0.000)
Age squared	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Group	0.887***	0.642***	0.020***	0.895***	0.648***	0.020***	0.895***	0.648***	0.020***
	(0.244)	(0.177)	(0.005)	(0.243)	(0.176)	(0.005)	(0.243)	(0.176)	(0.005)
Sales growth	0.386	0.279	0.009	0.394	0.285	0.009	0.394	0.285	0.009
	(0.269)	(0.194)	(0.006)	(0.269)	(0.194)	(0.006)	(0.269)	(0.194)	(0.006)
Export share	0.047***	0.034***	0.001***	0.047***	0.034***	0.001***	0.047***	0.034***	0.001***
	(0.004)	(0.003)	(0.000)	(0.004)	(0.003)	(0.000)	(0.004)	(0.003)	(0.000)
Constant	7.660***			6.743***			6.743***		
	(1.346)			(1.398)			(1.398)		
H_0 : Rating × $\text{year}_t = 0 \quad \forall \quad t < 2007$									
p-value							0.194		
Industry fixed effects	Yes			Yes			Yes		
Federal state fixed effects	Yes			Yes			Yes		
Year fixed effects	Yes			Yes			Yes		
Log likelihood	-23891.657			-23886.761			-23886.761		
Left-censored observations	2159			2159			2159		
Uncensored observations	6580			6580			6580		
Observations	8739			8739			8739		

Notes: Standard errors clustered by firm are reported in parentheses. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

We test for the common trend assumption of the difference-in-differences approach and analyze the effect heterogeneity by using a specification similar to Equation (5.1), but replace the dummy variables indicating the crisis or post-crisis periods by a set of year dummies for the years 2003 to 2012. This test serves as a test for the common trend assumption (Mora & Reggio 2015; Mora & Reggio 2019). Applying this approach, we follow recent applications (e.g. Hangoma et al. 2018; Miller 2018; Rowley et al. 2017). The common trend assumption holds if the joint test indicates that the interaction terms prior to 2007 are equal to zero. This is indeed the case, as shown by the relevant p-values of the test statistics at the bottom of Table 5.2, Column (7).[23] Moreover, Figure 5.3 plots the interaction effects and 95% confidence intervals. It becomes evident that there are no significant differences in the effects in the years 2003 to 2006 compared to the baseline period 2002. In the period of interest (2007 to 2009), a significant reduction in R&D occurs depending on the degree of financing constraints of firms in the years 2007 and 2009.

Figure 5.3: Impact of firm financing constraints on R&D over time



5.4.2 The effect of financing constraints dependent on the supply of external financing

Results of estimating Equation (5.1) separately for firms associated with banks with low or high capitalization are shown in Table 5.3. For firms which are related to a high capitalized bank, there is no difference in R&D spending during the financial crisis and the

[23] Detailed estimation results are shown in Table 5.8, Appendix 5.7.2.

period observed immediately thereafter compared to the pre-crisis period. This follows as the statistical insignificant coefficients of the interaction terms (Rating × Crisis and Rating × PostCrisis) indicate that the effects in these time periods are not different from that of Rating. In contrast, firms which are related to a bank that has only a limited ability to absorb shocks due to a low ratio of tangible common equity to tangible assets likewise suffer in the financial crisis period (Column 1). Similar results are obtained for the capital funds ratio (Columns 3, 4).[24]

Table 5.3: Impact of firm financing constraints on R&D accounting for bank differences

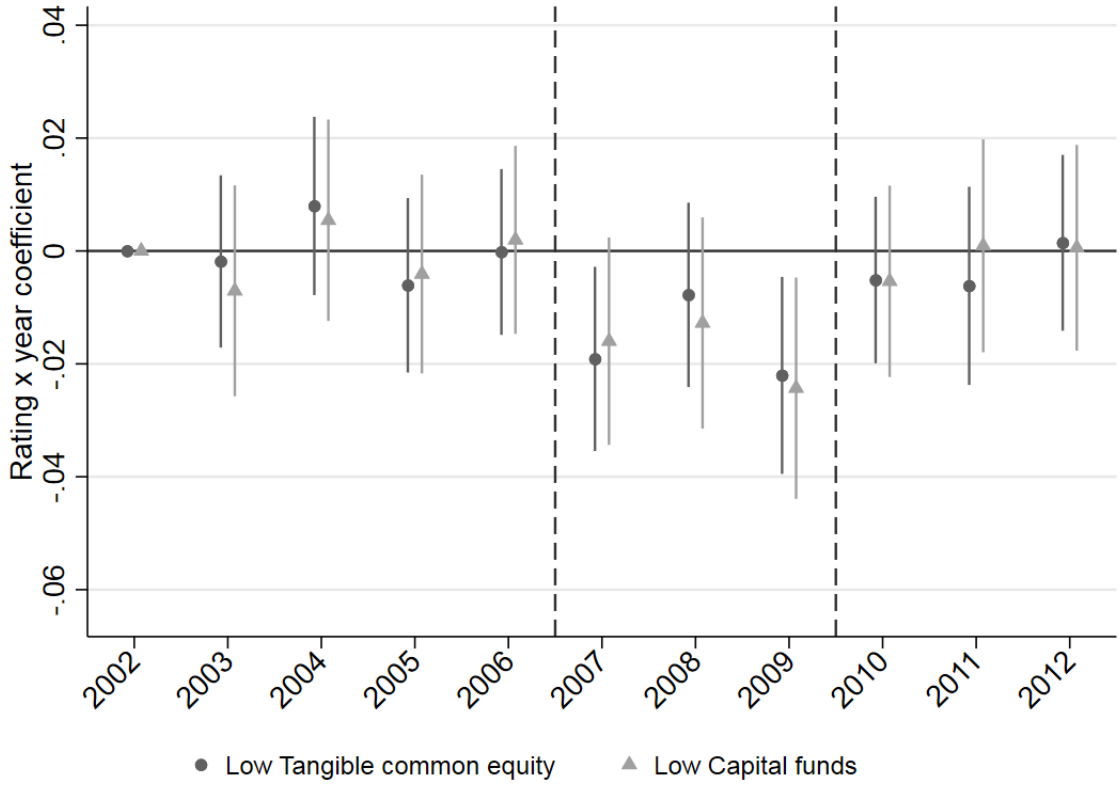
Dependent variable	(1)	(2)	(3)	(4)
	Tangible common equity		Capital funds	
	Low	High	Low	High
Rating	−0.011***	−0.014**	−0.012***	−0.010*
	(0.004)	(0.007)	(0.004)	(0.005)
Rating × Crisis	−0.015***	−0.008	−0.017***	−0.005
	(0.005)	(0.008)	(0.005)	(0.007)
Rating × PostCrisis	−0.004	−0.008	−0.002	−0.008
	(0.005)	(0.009)	(0.005)	(0.007)
Constant	6.769***	6.773***	6.856***	6.123***
	(1.790)	(2.446)	(1.843)	(2.181)
H_0 : Rating × $\text{year}_t = 0 \ \forall \ t < 2007$				
p-value	0.382	0.633	0.541	0.228
Firm controls	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes
Federal state fixed effects	Yes	Yes	Yes	Yes
Log Likelihood	−17481.776	−6331.509	−14402.936	−9394.914
Left-censored observations	1466	693	1166	993
Uncensored observations	4889	1691	4049	2531
Observations	6355	2384	5215	3524

Notes: Cluster-robust standard errors in parentheses, clustered at the firm level. Low indicates that the firm is related to a bank in the lower 25% of the variable's distribution of all German banks in the Bankscope data set. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

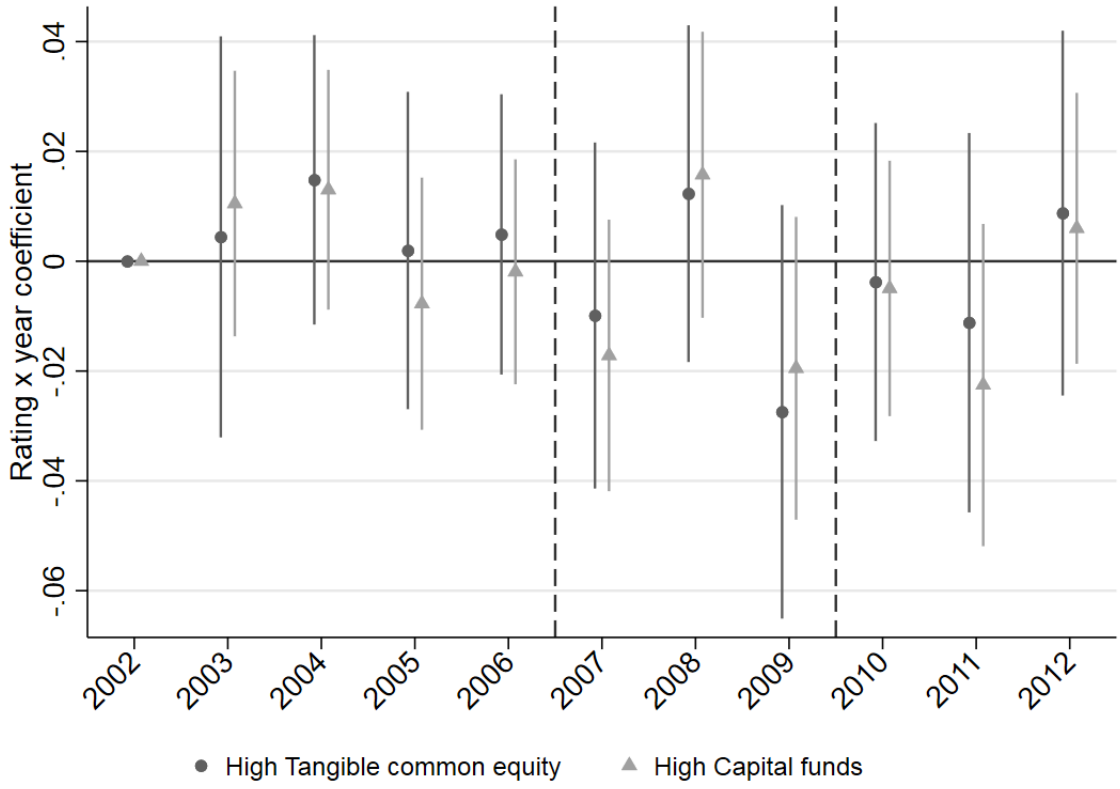
Again, we test for the common trend assumption by estimating Equation (5.1) but replacing the interaction terms by Rating times year interaction variables for the periods 2003 to 2012. The tests shown in the bottom row of Table 5.3 indicate that the common trend assumption holds as we cannot reject the null hypothesis that there is no joint significance of the pre 2007 interaction terms. This result is reinforced by the coefficient plots shown in Figure 5.4. We observe no difference in the effect in the period before 2007. However, in the time period of interest (2007 to 2009), we observe that the effect is different from the baseline period for firms which are related to a low-capitalized bank in the years 2007 and 2009. This relation does not hold for firms associated with high-capitalized banks.

[24]Detailed estimation results are shown in Tables 5.9, 5.10 and 5.11 in Appendix 5.7.3.

Figure 5.4: Impact of financing constraints on R&D over time dependent on bank capital



(a) Low bank capital



(b) High bank capital

Consequently, we observe heterogeneity in the effect of the financial crisis on constrained firms. It becomes evident that constraints exert an effect on both groups of firms in the pre-crisis period. However, the interaction term shows that the increase in intensity of constraints during the crisis is significantly higher for this group of firms than for the group of firms associated with a high capitalized bank. The differences in the effects between both groups of firms point towards an intensification of financing constraints due to the financial crisis rather than to an impact of the Basel II guidelines. This relation is assumed to hold as the Basel II regulations are expected to affect the importance of the ratings independently of the capital reserves of the banks.

5.4.3 The sensitivity of R&D to financing constraints and the role of subsidies

Besides bank financing, subsidies are an important source of financing for innovation (e.g. Almus & Czarnitzki 2003; Becker 2015; Bronzini & Piselli 2016; Clausen 2009; Czarnitzki & Lopes-Bento 2013; Howell 2017; Lach 2002; Zúñiga-Vicente et al. 2014). In that respect they also play an important role as a policy measure to mitigate the problems arising from the negative impact of financing constraints on R&D (e.g. Hall et al. 2016; Hyytinen & Toivanen 2005; Takalo & Tanayama 2010). Moreover, R&D subsidies can serve as a quality signal for suppliers of external financing, a factor which might increase their chances of obtaining external funding (e.g. Hottenrott et al. 2018; Kleer 2010; Meuleman & De Maeseneire 2012). However, in contrast to this positive effect of subsidies on R&D, it is argued that subsidy programs might lead to a crowding out of R&D investments (e.g. Busom 2000; Hud & Hussinger 2015; Lerner 2009). In this case, firms replace their private R&D investment with the money made available through R&D subsidies (Hud & Hussinger 2015). Thus, similar to the debate on bank financing, the effect of subsidies on R&D remains under discussion. Subsidies in the recent financial crisis are of particular interest as they could serve as a policy tool to overcome financing constraints of firms and banks. The German Federal Ministry for Education and Research (BMBF) increased its budget to react to the crisis (Hud & Hussinger 2015). Thus, it makes sense to account for the role of subsidies in our empirical approach.

We address the role of subsidies by providing the results of three tests. First, we re-estimate Equation (5.1) with the smaller sample for which we have information on subsidies. The results in Column (1) are comparable to those in Table 5.2. Next, we utilize the measure of subsidies and interact it with year dummies to account for a possible impact of a subsidy receipt in the specific year. The results of this test are shown in Table 5.4, Column (2). Accounting for the receipt of subsidies does not alter the results for financing constraints considerably. With respect to the coefficients of the subsidy variables, it is evident that firms which received subsidies realize higher R&D expenditures in the financial crisis and the period right after the crisis. This holds for the estimations when

we control for subsidies (Column (2)) and firms related to low-capitalized banks (Columns (3) and (5)).

Table 5.4: Impact of firm financing constraints on R&D accounting for yearly effects of subsidies

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable	Baseline	Control for Subsidies	Tangible common equity		Capital funds	
			Low	High	Low	High
Rating	−0.012***	−0.012***	−0.012**	−0.011	−0.011**	−0.011*
	(0.004)	(0.004)	(0.005)	(0.007)	(0.005)	(0.006)
Rating × Crisis	−0.014***	−0.012**	−0.016***	−0.009	−0.014**	−0.009
	(0.005)	(0.005)	(0.006)	(0.009)	(0.006)	(0.008)
Rating × PostCrisis	−0.005	−0.006	−0.004	−0.014	−0.003	−0.007
	(0.006)	(0.006)	(0.007)	(0.012)	(0.007)	(0.009)
Subsidy		3.761***	3.892***	3.651***	4.035***	3.465***
		(0.550)	(0.652)	(1.143)	(0.725)	(0.921)
Subsidy × 2003		1.018	0.285	2.139	0.048	2.527**
		(0.621)	(0.697)	(1.607)	(0.762)	(1.236)
Subsidy × 2004		0.032	−0.201	0.209	−0.306	0.072
		(0.614)	(0.734)	(1.387)	(0.800)	(1.089)
Subsidy × 2005		−0.057	−0.119	−0.664	0.139	−0.831
		(0.604)	(0.696)	(1.295)	(0.753)	(1.101)
Subsidy × 2006		−0.191	−0.127	−0.863	−0.239	−0.407
		(0.598)	(0.702)	(1.182)	(0.769)	(1.001)
Subsidy × 2007		1.395**	1.488**	0.851	1.535*	0.864
		(0.654)	(0.743)	(1.428)	(0.823)	(1.188)
Subsidy × 2008		1.341*	1.670**	0.457	1.665*	0.602
		(0.729)	(0.851)	(1.551)	(0.925)	(1.295)
Subsidy × 2009		1.786**	2.382***	−0.089	2.582***	0.163
		(0.712)	(0.827)	(1.502)	(0.916)	(1.265)

(*continued*)

Table 5.4: *Continued*

Dependent variable	(1) Baseline	(2) Control for Subsidies	(3) Tangible common equity	(4)	(5) Capital funds	(6)
			Low	High	Low	High
Subsidy × 2010		1.215*	1.219	1.155	1.679*	0.394
		(0.707)	(0.841)	(1.384)	(0.937)	(1.139)
Subsidy × 2011		1.234	1.561*	0.653	1.496	1.095
		(0.776)	(0.911)	(1.555)	(0.991)	(1.262)
Subsidy × 2012		1.407*	1.857**	0.632	1.877*	1.141
		(0.806)	(0.937)	(1.670)	(1.035)	(1.379)
Constant	6.377***	6.023***	6.335***	4.351	5.972***	4.680*
	(1.773)	(1.582)	(2.013)	(2.770)	(1.984)	(2.704)
H_0 : Rating × year$_t = 0 \ \forall \ t < 2007$						
p-value	0.210	0.163	0.213	0.548	0.549	0.548
H_0 : Subsidy × year$_t = 0 \ \forall \ t < 2007$						
p-value		0.330	0.952	0.352	0.908	0.352
Firm controls	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Federal state fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Log Likelihood	-16564.662	-16234.468	-11960.996	-4185.124	-9940.564	-6193.535
Left-censored observations	1634	1634	1136	498	889	745
Uncensored observations	4514	4514	3374	1140	2839	1675
Observations	6148	6148	4510	1638	3728	2420

Notes: Cluster-robust standard errors in parentheses, clustered at the firm level. Low indicates that the firm is related to a bank in the lower 25% of the variable's distribution of all German banks in the Bankscope data set. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

As a second test, we estimate Equation (5.1) for subsidy and non-subsidy recipients separately. Results of this test are shown in Table 5.5, Columns (1) to (6). Without consideration of the capital endowment of the main banks of the firms, the results are as follows: The interaction of the rating variable with the Crisis dummy appears to be significant only for the sample of firms which received no subsidy. For those firms which received a subsidy, financially constrained firms show no enhanced sensitivity to financing constraints in the financial crisis or the period after the financial crisis. The test on the bottom of Table 5.5 reveals that we cannot reject the null hypothesis that the pre-crisis interaction terms of the rating and year variables jointly exert no effect. Thus, the common trend assumption is met in every case.

Next, we test whether the results for the previous test also hold when considering firms which are related to a low-capitalized bank (Columns (3) to (6)). These firms are those which suffer the most due to firm and bank financing constraints. Thus, this test informs whether firms which receive subsidies show a lower or even no enhanced sensitivity to firm financing constraints in the crisis although they are related to a low-capitalized bank. For this purpose, we estimate Equation (5.1) for the subsamples of firms which are related to a low-capitalized bank and receive subsidies, as well as firms which are related to a low-capitalized bank and do not receive subsidies. As shown in Table 5.5, firms which are related to a low-capitalized bank but are subsidy recipients do not suffer from stronger constraints in the financial crisis. For those firms which do not receive subsidies, the spending on R&D constraints in the crisis period compared to the period before depends on their degree of firm financing.

Table 5.5: Impact of firm financing constraints on R&D accounting for yearly effects of subsidies

Dependent variable	(1)	(2)	(3)	(4)	(5)	(6)
	Baseline		Low Tangible common equity		Low Capital funds	
	Subsidy	No-subsidy	Subsidy	No-subsidy	Subsidy	No-subsidy
Rating	−0.014***	−0.008	−0.017***	−0.008	−0.012**	−0.007
	(0.003)	(0.007)	(0.004)	(0.008)	(0.005)	(0.009)
Rating × Crisis	−0.003	−0.022***	−0.003	−0.028***	0.000	−0.026**
	(0.004)	(0.008)	(0.005)	(0.010)	(0.005)	(0.010)
Rating × PostCrisis	0.003	−0.015	0.005	−0.010	0.002	−0.012
	(0.005)	(0.010)	(0.005)	(0.012)	(0.005)	(0.013)
Constant	14.327***	1.935	15.602***	1.397	13.968***	0.686
	(1.080)	(2.540)	(1.440)	(3.251)	(1.513)	(3.346)
H_0 : Rating × $\text{year}_t = 0 \ \ \forall \ \ t < 2007$						
p-value	0.094	0.207	0.345	0.178	0.387	0.558
Firm controls	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Federal state fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Log Likelihood	-6050.959	-9398.029	-4765.126	-6538.910	-3926.868	-5327.113
Left-censored observations	170	1464	131	1005	92	797
Uncensored observations	2185	2329	1739	1635	1495	1344
Observations	2355	3793	1870	2640	1587	2141

Note: Cluster-robust standard errors in parentheses, clustered at the firm level. Low indicates that the firm is related to a bank in the lower 25% of the variable's distribution of all German banks in the Bankscope data set. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

5.5 Robustness and sensitivity tests

5.5.1 Endogenous firm-bank matching and sample selection

A possible problem of our empirical specification is that the affiliation of banks and firms may not be random. On the one hand, banks differ in terms of their risk policies (e.g. regarding orientation towards capital accumulation).[25] On the other hand, firms also pursue varying risk strategies and an important factor here is the decision for or against R&D. A possible consequence of this would be the association of banks and companies with an affinity for risk (and vice versa), as risk-affine banks are prepared to finance risky projects. The possible endogenous matching process could affect the impact of the crisis on research-intensive companies. Consequently, a selectivity problem might exist.

To account for this selectivity problem, we use an inverse probability weighting (IPW) approach (e.g. Abadie & Cattaneo 2018; Imbens & Wooldridge 2009). First, we estimate the probability of each firm to be related to a low or high-capitalized bank by accounting for the impact of the firm's creditworthiness in each year. In the second step, we calculate the inverse probability weight from the obtained propensity score. Finally, we estimate Equation (5.1) and perform the regressions for firms related to high and low-capitalized banks separately and weight the observations by the generated weight. This has two advantages. Firstly, the re-weighting is supposed to eliminate potential differences between both types of firms by equalizing the explanatory variables. Secondly, the IPW approach is helpful to reduce the selection bias which results from the sample splitting approach in Section 5.4.2 (e.g. Wooldridge 2002; Wooldridge 2007).[26] The results for the Probit estimation, indicating whether firms are related to a high or low-capitalized bank, are shown in Appendix 5.7.4, Table 5.12. The corresponding test on the difference in mean of the explanatory variables after re-weighting is shown in Table 5.13 of Appendix 5.7.4. It becomes evident that there are no differences in means of the explanatory variables after the weighting. Table 5.14 shows the estimation results for the re-weighted regressions. The results look fairly similar to the estimates in Tables 5.2, 5.3.

5.5.2 Model and dependent variable

We provide several robustness tests for our analysis. Results for these are shown in Appendix 5.7.5. First, we provide general tests concerning the model dependence of our results. Thus, we re-estimate the results of Tables 5.2, 5.3 using homoscedastic Tobit and OLS. The results are comparable to the estimates in Tables 5.2, 5.3 as shown in Panels A and B of Table 5.15 in Appendix 5.7.5. Moreover, we re-estimate our results using the

[25] See e.g. Schwert (2018), Calem & Rob (1999), Furlong & Keeley (1989).

[26] Applying Heckman selection models to correct for the sample selection does not alter the results considerably. This holds for sample selection model with a linear model in the second step as well as with a Tobit model to account for corner solutions in the second step.

logarithm of the share of R&D expenditures per employee (Table 5.15, Panel C, Appendix 5.7.5). Again, we observe similar results (Appendix 5.7.5, Table 5.15). Additionally, we perform tests concerning the variables included in the heteroscedasticity term. The results for these tests (e.g. adding the remainder control variables) are shown in Table 5.16, Panels B, C and D and are fairly similar to the baseline results in Tables 5.2, 5.3.

5.5.3 Changes to the rating variable

Second, we test for the robustness of specification of our proxy for firm financing constraints, the rating variable. For this purpose, we start by using the one period lagged rating value as it is common practice in the literature (e.g. Czarnitzki & Hottenrott 2011a; Czarnitzki & Hottenrott 2011b) to determine whether firms are financially constrained. In line with this strand of literature, we assume that the lagged rating measure is exogenously determined. The advantage of this modified rating variable is its variation over time. The results shown in Panel A of Table 5.17 are comparable to the benchmark results presented in Table 5.2 and the results for the bank capital differentiation in Table 5.3. Next, we use the mean value of the firm's ratings in the three years prior to the Basel II guidelines (2004 to 2006). Again, we observe similar results (Tables 5.17, Panel B, Appendix 5.7.6). Last, we provide the results for an extended sample in which we re-add the firms which have rating values of 500 or above. As shown in Panel C of Table 5.17 in Appendix 5.7.6, these results are comparable to the ones shown in Tables 5.2, 5.3.

5.5.4 Changes concerning bank related information

Third, we provide tests for the heterogeneity of our results concerning the supplier of external financing – the main banks. In a first step, we apply two specifications with cut-off points at 10% and 50% of the distributions of all banks in the Bankscope data set that are observed in the year 2006. The results are shown in Table 5.18, Panel A and B in Appendix 5.7.7 and they are quite similar to the results presented in Table 5.3. A second test in this respect comprises the firm-bank relationship. Therefore, we drop firms from our sample that switched their main bank in any year of the sample period. We use the remainder of 5765 observations and re-estimate our results. As shown in Panel C of Table 5.18 in Appendix 5.7.7, the results of both estimations are comparable to the results presented in Tables 5.2, 5.3. Last, we use additional definitions for the capitalization of banks. First, we apply the alternative measure of equity to total assets, which is the inverse of the bank leverage ratio as described above. Second, we use the value of capital funds to net loans (Avdjiev et al. 2019). Results based on these variables and the cut-off point at 25% are shown in Table 5.19 of Appendix 5.7.7. They are fairly similar to the estimates in Table 5.3.

5.5.5 Sample size and time period definition

We perform various tests which concern the definition of the crisis and pre-crisis periods. Table 5.20 in Appendix 5.7.8 shows the corresponding results. First, we replace the crisis dummy (years 2007 to 2009) by a Basel dummy (2007) and Crisis dummy (2008 and 2009). The results are shown in Table 5.20, Panel A and are similar to the baseline results. Next, we account for the early 2000s recession – a period for Germany that was characterized by decreasing GDP growth and a recession in 2003 (Dustmann et al. 2014). Thus, we include a dummy for this pre-crisis downturn. As the first year in our sample is 2002, the dummy takes unit value in the years 2002 and 2003. As the downturn was likely not related to financial market issues[27], no effect is found for the interaction with the Rating variable (Table 5.20, Panel B). In additional tests, which are shown in Table 5.21 of Appendix 5.7.8, we deleted the years 2002 and 2003 (Panel A) and 2002 to 2004 (Panel B). This does not affect our results either.

5.5.6 Selection in the subsidy recipient status and definition of the subsidy variable

In addition to the previous tests, we also apply robustness tests with respect to the analysis including the differentiation of subsidy recipients and those firms which did not receive a subsidy. First, we address a potential selection problem as firms with special characteristics are likely subsidy recipients and therefore realize different R&D expenditures than firms which do not receive a subsidy (e.g. Hud & Hussinger 2015). Thus, we again apply the two-step approach mentioned in Section 5.5.1 and first estimate a Probit equation to obtain the predicted probability of receiving a subsidy. In the next step, we calculate inverse probability weights and re-weight the results from Tables 5.4, 5.5. Results for the Probit estimation are shown in Table 5.22, Appendix 5.7.9. The comparison of the weighted means of the control variables is shown in Table 5.23, Appendix 5.7.9 and implies that the sample is fairly balanced after weighting. The re-estimation results are shown in Appendix 5.7.9, Tables 5.24, 5.25 and are similar to the results presented in Tables 5.4 and 5.5.

We also consider the construction of the subsidy variable. The applied measure is not free of limitations (e.g. firms might switch between subsidy and no-subsidy status over time). As the definition of what makes a firm a subsidy recipient is important, we perform additional tests with alternative definitions of the subsidy measure. Thus, we classify firms as subsidy recipients if they received a subsidy (i) in any time period of the sample period (2002-2012) or (ii) in the pre-crisis period (2002-2006). The results of the re-estimation of Equation (5.1) when accounting for subsidies (Table 5.4) with the new definitions of

[27] See e.g. Cingano et al. 2016 who uses the early 2000s period as a placebo period for a shock to financial markets.

the subsidy variable (i) and (ii) are shown in Appendix 5.7.9, Table 5.26 (Panel A and B). Additionally, the estimations of Equation (5.1) for firms that received a subsidy and those that did not (Table 5.5) are shown in Table 5.27 (Panel A and B) for the alternative subsidy definitions (i) and (ii). It becomes evident that the results are comparable to the baseline estimates in Tables 5.4 and 5.5.[28]

5.6 Conclusion

The impact of credit constraints for firms on R&D has been investigated for some time now (e.g. Czarnitzki & Hottenrot 2010; Hall et al. 2016; He & Tian 2018). We extend this topic by taking two kinds of differentiation into account: the role of economic conditions in general and the impact of constraints of banks themselves. Economic conditions are considered by comparing the time of the financial crisis, as then demand and supply of debt was drastically affected, with periods before and afterwards. The impact of constraints of banks is included by taking up their bank balance sheet strength in terms of bank capital.

Our results clearly indicate that financial constraints matter for R&D in general and become more relevant during the financial crisis.[29] Firms with financing constraints reduce their R&D spending to a larger extent than less constrained firms during the crisis period, compared to the period before. With respect to the most important supplier of debts, namely the banks, it becomes obvious that banks with weaker balance sheets transmit their problems to their corporate customers. Thus, firms related to a bank with a weak capital endowment reduce their R&D spending in the financial crisis in accordance with their financing constraints. This effect is not observed for firms related to a high-capitalized bank. The consideration of bank constraints indicates that the financial crisis, rather than the Basel II enactment, was responsible for the sharper reduction in R&D expenditures. Thus, our results clearly imply an impact of bank financing on R&D.

The results point to a need for more research on the risk attitudes of banks. Thus, in line with the recent development of capital buffer due to the Basel II and III guidelines, the importance of considering bank capital is underlined by our results. Consequently, an implication for policy makers which might be drawn from our results is that strengthening the bank balance sheet is an important device to achieve stability in times of turbulence on financial markets. As holding capital is costly, it might be difficult to find a balance

[28] Similar results are obtained if we classify the firms as subsidy recipient if they received a subsidy (i) in the pre-crisis or crisis period (2002-2010) or (ii) in the crisis period (2007-2009). Moreover, we achieve similar results if we define firms as subsidy recipient if they received a subsidy from German states or national governments.

[29] Our results coincide with findings of other work utilizing periods which do not include the financial crisis (e.g. Czarnitzki & Hottenrot 2010; Hall et al. 2016; He & Tian 2018). Moreover, our findings are related to literature which investigates the impact of the crisis on innovation utilizing German data (e.g. Hud & Hussinger 2015; Kulicke et al. 2010; Rammer 2011).

between costs of capital in normal times and the benefits in times of downturn (Adrian et al. 2018; Thakor 2014).

With respect to the impact of subsidies, our findings show that firms which receive subsidies benefit with respect to their R&D expenditures. This finding is in line with the previous studies which investigate the impact of subsidies in the recent financial crisis on firm R&D (e.g. Hud & Hussinger 2015). Extending the existing approaches by considering financing constraints, our results add further to this strand of literature. Concerning financing constraints, the results imply that firms which received a subsidy did not suffer from a stronger impact of financing constraints on R&D in the financial crisis. Moreover, firms which are related to a low-capitalized bank also show no larger intensity of financing constraints for R&D in the financial crisis if they are classified as subsidy recipient. This result shows that subsidies mitigate financing constraints.

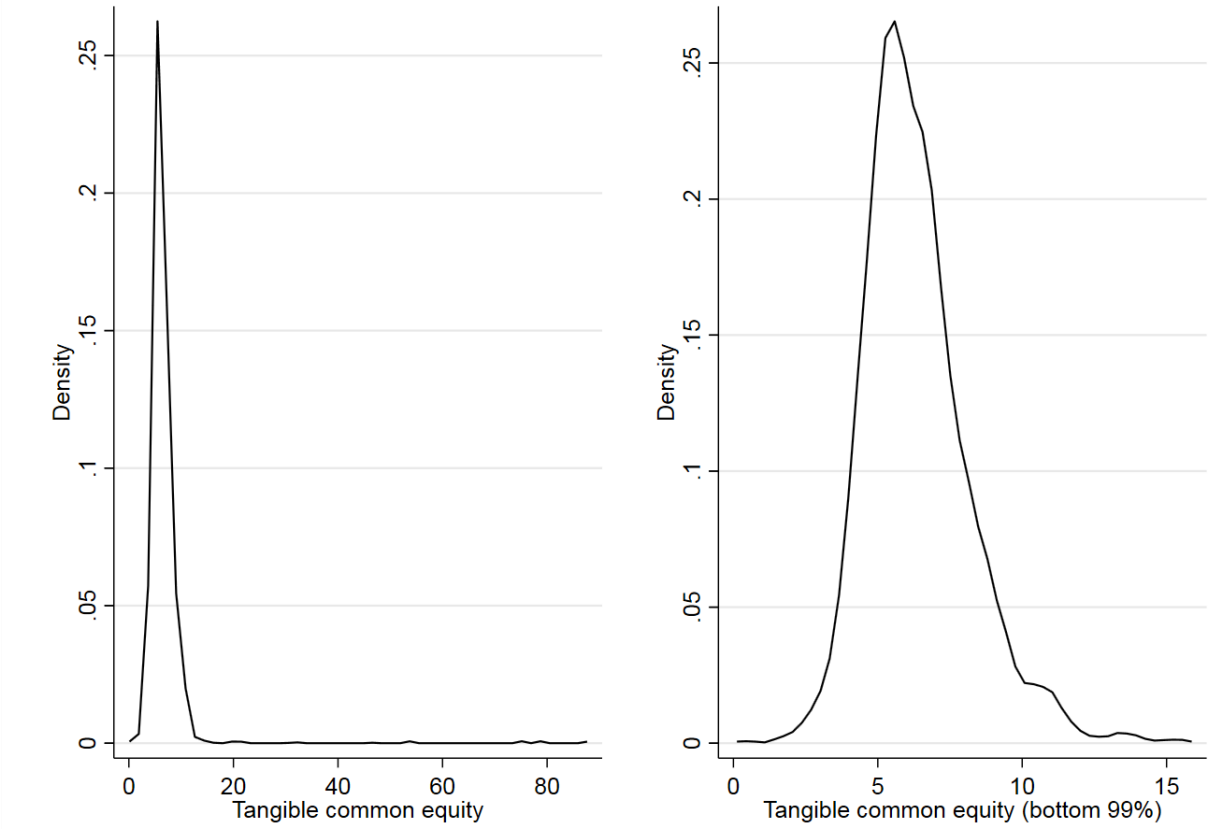
We can also draw from our analysis several policy implications at the firm level. The cumulative public and private expenditures for R&D are below the EU policy target level of 3% of GDP (OECD 2018). The European Commission (2010a) and European Commission (2010b) point to the importance of access to finance in order to realize innovation activities and, to this end, two additional sources of external finance must be considered: subsidies and venture capital. First, as highlighted by the literature on R&D subsidies, due to their influence on the growth of an economy it is essential to provide financial support to innovative firms (e.g. Brautzsch et al. 2015; Hud & Hussinger 2015).[30] Second, it might be important to support firms especially during times of difficult financing conditions, when banks are particularly cautious and will minimize their risks by reducing lending to innovative firms. In such periods public subsidies are especially valuable. Second, another implication is the strengthening of venture capital financing. Even if this type of financing might be the least preferred by established firms, it is a valuable source of funding for younger firms (Brown et al. 2012; Hochberg et al. 2018). However, in Germany, the opportunities for venture capital financing are sparse. Third, another option would be that firms make use of equity issuance to finance innovation (Brown et al. 2009; Lerner et al. 2011). However, like bank financing, equity financing contracted during the crisis (Kahle & Stulz 2013).

[30]See e.g. Hottenrott & Lopes-Bento (2014) for an evaluation of the effectivity of a targeted subsidy program.

5.7 Appendix

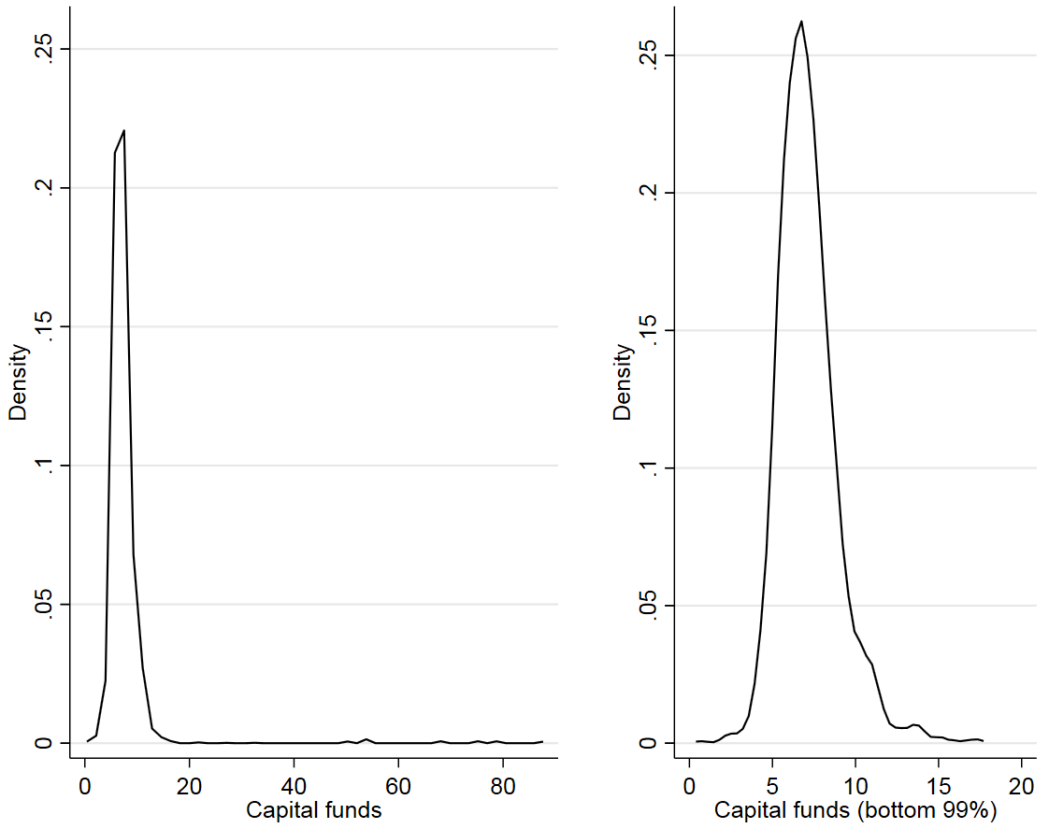
5.7.1 Descriptive statistics

Figure 5.5: Distribution of the tangible common equity ratio



Notes: The figure shows the distribution of the tangible common equity ratio over 1452 banks (left) from the Bankscope data set. The right diagram shows the distribution for the bottom 99% of the banks.

Figure 5.6: Distribution of the capital funds ratio



Notes: The figure shows the distribution of the capital funds ratio over 1452 banks (left) from the Bankscope data set. The right diagram shows the distribution for the bottom 99% of the banks.

Table 5.6: Distribution of firms over industries

Name	NACE Rev. 2.0 code	Firms	Percentage share
Mining	5-9, 19, 35	96	2.952
Food/Tobacco	10-12	120	3.690
Textiles	13-15	132	4.059
Wood/Paper	16-17	110	3.383
Chemicals	20-21	218	6.704
Plastics	22	157	4.828
Glass/Ceramics	23	93	2.860
Metals	24-25	296	9.102
Electrical equipment	26-27	489	15.037
Machinery	28	374	11.501
Retail/Automobile	29-30	129	3.967
Furniture /Toys/Medical technology/Maintenance	31-33	235	7.226
Energy / Water	36-39	66	2.030
Media services	18, 58-60	98	3.014
IT/Telecommunications	61-63	256	7.872
Technical services/R&D services	71-72	288	8.856
Consulting/Advertising	69, 70.2, 73	95	2.921
Total		3252	100.000

Table 5.7: Distribution of firms over federal states

Name	Firms	Percentage share
Baden-Wuerttemberg	496	15.252
Bavaria	457	14.053
Berlin	122	3.752
Brandenburg	120	3.690
Bremen	53	1.630
Hamburg	57	1.753
Hesse	195	5.996
Lower Saxony	230	7.073
Mecklenburg-Vorpommern	58	1.784
North Rhine-Westphalia	558	17.159
Rhineland-Palatinate	109	3.352
Saarland	31	0.953
Saxony	355	10.916
Saxony-Anhalt	145	4.459
Schleswig-Holstein	62	1.907
Thuringia	204	6.273
Total	3252	100.000

5.7.2 Additional results and marginal effects for the baseline estimation

Table 5.8: Common trend test and effect heterogeneity

	(1)	(2)	(3)	(4)
Rating	−0.023***	−0.020***	−0.013**	−0.011***
	(0.006)	(0.004)	(0.006)	(0.003)
Rating × 2003	−0.003		−0.002	
	(0.008)		(0.007)	
Rating × 2004	0.012		0.009	
	(0.007)		(0.007)	
Rating × 2005	−0.002		−0.004	
	(0.008)		(0.007)	
Rating × 2006	0.002		0.002	
	(0.007)		(0.007)	
Rating × 2007	−0.014*	−0.017***	−0.015**	−0.017***
	(0.008)	(0.006)	(0.008)	(0.006)
Rating × 2008	−0.003	−0.005	−0.003	−0.004
	(0.008)	(0.006)	(0.007)	(0.006)
Rating × 2009	−0.020**	−0.023***	−0.022***	−0.024***
	(0.009)	(0.007)	(0.008)	(0.007)
Rating × 2010	−0.003	−0.006	−0.005	−0.006
	(0.007)	(0.005)	(0.007)	(0.005)
Rating × 2011	−0.009	−0.011	−0.007	−0.009
	(0.009)	(0.007)	(0.008)	(0.007)
Rating × 2012	0.002	0.000	0.004	0.003
	(0.008)	(0.006)	(0.007)	(0.006)
Constant	10.195***	9.596***	7.096***	6.736***
	(1.815)	(1.449)	(1.718)	(1.397)
H_0 : Rating × $\text{year}_t = 0 \ \ \forall \ \ t < 2007$				
p-value	0.107		0.194	
H_0 : Rating × $\text{year}_t = 0 \ \ \forall \ \ t < 2012$				
p-value	0.006		0.003	
Firm controls	-	-	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes
Federal state fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Log Likelihood	-24177.002	-24179.376	-23880.642	-23882.502
Left censored observations	2159	2159	2159	2159
Uncensored observations	6580	6580	6580	6580
Observations	8739	8739	8739	8739

Notes: Cluster-robust standard errors in parentheses, clustered at the firm level. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

5.7.3 Detailed and additional results for the estimations with bank splits

Table 5.9: Estimation results with all variables included based on tangible common equity splitting

	(1)	(2)	(3)	(4)	(5)	(6)
		Low			High	
Rating	−0.016***		−0.011***	−0.018***		−0.014**
	(0.003)		(0.004)	(0.006)		(0.007)
Rating × Pre-Crisis		−0.011***			−0.014**	
		(0.004)			(0.007)	
Rating × Crisis		−0.026***	−0.015***		−0.022***	−0.008
		(0.005)	(0.005)		(0.008)	(0.008)
Rating × PostCrisis		−0.014***	−0.004		−0.022**	−0.008
		(0.004)	(0.005)		(0.009)	(0.009)
Size	0.849***	0.837***	0.837***	1.202***	1.194***	1.194***
	(0.111)	(0.112)	(0.112)	(0.351)	(0.362)	(0.362)
Size squared	−0.015***	−0.015***	−0.015***	−0.032***	−0.032***	−0.032***
	(0.003)	(0.003)	(0.003)	(0.010)	(0.011)	(0.011)
Age	−0.024	−0.024*	−0.024*	−0.052**	−0.053**	−0.053**
	(0.015)	(0.015)	(0.015)	(0.024)	(0.024)	(0.024)
Age squared	0.000*	0.000*	0.000*	0.000**	0.000**	0.000**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Group	0.740***	0.751***	0.751***	1.080**	1.079**	1.079**
	(0.280)	(0.280)	(0.280)	(0.474)	(0.473)	(0.473)
Sales growth	0.319	0.317	0.317	0.635	0.675	0.675
	(0.295)	(0.295)	(0.295)	(0.682)	(0.680)	(0.680)
Export share	0.043***	0.043***	0.043***	0.054***	0.054***	0.054***
	(0.005)	(0.005)	(0.005)	(0.008)	(0.008)	(0.008)
Constant	7.796***	6.769***	6.769***	7.648***	6.773***	6.773***
	(1.731)	(1.790)	(1.790)	(2.350)	(2.446)	(2.446)
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Federal state fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Log Likelihood	-17487.261	-17481.776	-17481.776	-6332.266	-6331.509	-6331.509
Left censored observations	1466	1466	1466	693	693	693
Uncensored observations	4889	4889	4889	1691	1691	1691
Observations	6355	6355	6355	2384	2384	2384

Notes: Low indicates that the firm is related to a bank in the lower 25% of the variable's distribution of all German banks in the Bankscope data set. Cluster-robust standard errors in parentheses, clustered at the firm level. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

Table 5.10: Estimation results with all variables included based on capital funds splitting

	(1)	(2)	(3)	(4)	(5)	(6)
		Low			High	
Rating	−0.017***		−0.012***	−0.014***		−0.010*
	(0.003)		(0.004)	(0.005)		(0.005)
Rating × Pre-Crisis		−0.012***			−0.010*	
		(0.004)			(0.005)	
Rating × Crisis		−0.028***	−0.017***		−0.015**	−0.005
		(0.005)	(0.005)		(0.007)	(0.007)
Rating × PostCrisis		−0.014***	−0.002		−0.018***	−0.008
		(0.004)	(0.005)		(0.007)	(0.007)
Size	0.766***	0.757***	0.757***	1.409***	1.406***	1.406***
	(0.105)	(0.105)	(0.105)	(0.324)	(0.329)	(0.329)
Size squared	−0.014***	−0.013***	−0.013***	−0.035***	−0.035***	−0.035***
	(0.002)	(0.002)	(0.002)	(0.009)	(0.009)	(0.009)
Age	−0.014	−0.015	−0.015	−0.056***	−0.056***	−0.056***
	(0.016)	(0.016)	(0.016)	(0.020)	(0.020)	(0.020)
Age squared	0.000	0.000	0.000	0.000***	0.000***	0.000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Group	0.909***	0.925***	0.925***	0.694*	0.702*	0.702*
	(0.315)	(0.315)	(0.315)	(0.363)	(0.362)	(0.362)
Sales growth	0.156	0.164	0.164	0.740	0.755*	0.755*
	(0.332)	(0.332)	(0.332)	(0.456)	(0.455)	(0.455)
Export share	0.041***	0.041***	0.041***	0.052***	0.052***	0.052***
	(0.005)	(0.005)	(0.005)	(0.007)	(0.007)	(0.007)
Constant	7.813***	6.856***	6.856***	6.904***	6.123***	6.123***
	(1.766)	(1.843)	(1.843)	(2.126)	(2.181)	(2.181)
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Federal state fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Log Likelihood	-14408.755	-14402.936	-14402.936	-9395.679	-9394.914	-9394.914
Left censored observations	1166	1166	1166	993	993	993
Uncensored observations	4049	4049	4049	2531	2531	2531
Observations	5215	5215	5215	3524	3524	3524

Notes: Low indicates that the firm is related to a bank in the lower 25% of the variable's distribution of all German banks in the Bankscope data set. Cluster-robust standard errors in parentheses, clustered at the firm level. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

Table 5.11: Common trend test and effect heterogeneity based on capital splitting

	(1)	(2)	(3)	(4)
	Tangible common equity		Capital funds	
	Low	High	Low	High
Rating	−0.011*	−0.020	−0.012	−0.013
	(0.006)	(0.012)	(0.008)	(0.010)
Rating × 2003	−0.002	0.004	−0.007	0.011
	(0.008)	(0.019)	(0.010)	(0.012)
Rating × 2004	0.008	0.015	0.005	0.013
	(0.008)	(0.013)	(0.009)	(0.011)
Rating × 2005	−0.006	0.002	−0.004	−0.008
	(0.008)	(0.015)	(0.009)	(0.012)
Rating × 2006	0.000	0.005	0.002	−0.002
	(0.007)	(0.013)	(0.008)	(0.010)
Rating × 2007	−0.019**	−0.010	−0.016*	−0.017
	(0.008)	(0.016)	(0.009)	(0.013)
Rating × 2008	−0.008	0.012	−0.013	0.016
	(0.008)	(0.016)	(0.010)	(0.013)
Rating × 2009	−0.022**	−0.027	−0.024**	−0.019
	(0.009)	(0.019)	(0.010)	(0.014)
Rating × 2010	−0.005	−0.004	−0.005	−0.005
	(0.008)	(0.015)	(0.009)	(0.012)
Rating × 2011	−0.006	−0.011	0.001	−0.023
	(0.009)	(0.018)	(0.010)	(0.015)
Rating × 2012	0.001	0.009	0.001	0.006
	(0.008)	(0.017)	(0.009)	(0.013)
Constant	6.900***	8.173**	6.884***	6.690**
	(2.056)	(3.357)	(2.229)	(2.899)
H_0 : Rating × $\text{year}_t = 0 \ \forall \ t < 2007$				
p-value	0.382	0.633	0.541	0.228
H_0 : Rating × $\text{year}_t = 0 \ \forall \ t < 2012$				
p-value	0.026	0.425	0.050	0.048
Firm controls	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes
Federal state fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Log Likelihood	-17478.411	-6327.529	-14401.005	-9385.943
Left censored observations	1466	693	1166	993
Uncensored observations	4889	1691	4049	2531
Observations	6355	2384	5215	3524

Notes: Low indicates that the firm is related to a bank in the lower 25% of the variable's distribution of all German banks in the Bankscope data set. Cluster-robust standard errors in parentheses, clustered at the firm level. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

5.7.4 Endogeneous firm-bank matching and sample selection

Table 5.12: Matching results to obtain the propensity score for the construction of the inverse probability weights

	(1)	(2)
Dependent variable	Low Tangible Common Equity	Low Capital Funds
Rating	−0.003**	−0.005***
	(0.001)	(0.001)
Rating × 2003	0.000	0.002
	(0.002)	(0.002)
Rating × 2004	0.002	0.003*
	(0.002)	(0.002)
Rating × 2005	0.000	0.003*
	(0.002)	(0.002)
Rating × 2006	0.001	0.004**
	(0.002)	(0.002)
Rating × 2007	0.002	0.002
	(0.002)	(0.002)
Rating × 2008	0.000	0.003
	(0.002)	(0.002)
Rating × 2009	0.002	0.003*
	(0.002)	(0.002)
Rating × 2010	0.001	0.004**
	(0.002)	(0.002)
Rating × 2011	0.002	0.003
	(0.002)	(0.002)
Rating × 2012	0.002	0.003
	(0.002)	(0.002)
Size	0.108***	0.106***
	(0.033)	(0.027)
Size squared	−0.002***	−0.002***
	(0.001)	(0.001)
Age	0.002	0.000
	(0.002)	(0.002)
Age squared	0.000	0.000
	(0.000)	(0.000)
Group	0.417***	0.396***
	(0.035)	(0.032)
Sales growth	−0.008	−0.081
	(0.064)	(0.060)
Export share	0.005***	0.004***
	(0.001)	(0.001)
Constant	0.501	0.952***
	(0.337)	(0.324)
Log likelihood	-4197.067	-5125.850
Observations	8739	8739

Note: Treatment status is defined as being related to a low capitalized bank. Each regression includes industry times federal state fixed effects. Standard errors in parentheses. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

Table 5.13: Mean comparison after matching – Means calculated using inverse probability weights

	Mean		Difference	p-value
Variable	Control	Treated		
Panel A: Tangible Common Equity				
Rating	217.559	216.401	−1.157	0.505
Rating × 2003	9.253	10.954	1.701	0.199
Rating × 2004	19.229	20.683	1.454	0.542
Rating × 2005	18.494	18.487	−0.007	0.998
Rating × 2006	24.281	23.999	−0.282	0.918
Rating × 2007	18.882	21.027	2.145	0.281
Rating × 2008	24.863	25.850	0.986	0.675
Rating × 2009	12.759	14.504	1.745	0.285
Rating × 2010	37.092	27.729	−9.363	0.120
Rating × 2011	15.625	16.303	0.678	0.722
Rating × 2012	20.532	21.404	0.872	0.704
Size	0.470	0.342	−0.128	0.493
Size Squared	7.408	4.284	−3.125	0.615
Age	30.359	31.011	0.652	0.546
Age squared	1878.887	1959.242	80.355	0.519
Part of firm group	0.498	0.492	−0.007	0.777
Sales growth	0.060	0.063	0.004	0.829
Export share	24.057	24.016	−0.041	0.970
Panel B: Capital Funds				
Rating	216.636	217.214	0.577	0.641
Rating × 2003	11.388	11.118	−0.270	0.865
Rating × 2004	21.206	20.763	−0.443	0.813
Rating × 2005	18.200	18.445	0.245	0.876
Rating × 2006	23.132	23.863	0.732	0.690
Rating × 2007	19.612	20.879	1.267	0.410
Rating × 2008	24.670	25.864	1.194	0.495
Rating × 2009	13.432	14.364	0.932	0.474
Rating × 2010	28.383	27.946	−0.437	0.830
Rating × 2011	16.372	16.549	0.177	0.909
Rating × 2012	22.763	21.866	−0.897	0.718
Size	0.484	0.347	−0.137	0.258
Size Squared	7.796	4.445	−3.350	0.368
Age	30.643	30.741	0.099	0.904
Age squared	1926.061	1945.922	19.861	0.855
Group	0.506	0.491	−0.015	0.285
Sales growth	0.073	0.065	−0.008	0.330
Export share	24.150	24.027	−0.124	0.870

Table 5.14: Weighted estimations for the impact of firm financing constraints on R&D accounting for bank differences

	(1)	(2)	(3)
	Baseline	Tangible common equity	
		Low	High
Panel A: Tangible Common Equity			
Rating	−0.016***	−0.012***	−0.025***
	(0.004)	(0.004)	(0.007)
Rating × Crisis	−0.013**	−0.012**	−0.014
	(0.005)	(0.005)	(0.009)
Rating × PostCrisis	−0.008	−0.002	−0.008
	(0.007)	(0.005)	(0.012)
Constant	8.067***	6.494***	9.305***
	(1.412)	(1.916)	(2.115)
Observations	8613	6229	2384
Panel B: Capital Funds			
	Baseline	Capital Funds	
		Low	High
Rating	−0.014***	−0.013***	−0.017***
	(0.003)	(0.005)	(0.005)
Rating × Crisis	−0.012**	−0.014**	−0.007
	(0.005)	(0.006)	(0.008)
Rating × PostCrisis	−0.002	0.002	−0.003
	(0.005)	(0.006)	(0.008)
Constant	8.143***	6.796***	9.338***
	(1.344)	(1.919)	(1.852)
Observations	8693	5169	3524

Notes: All estimations include firm controls as described in Section 5.3.1. Moreover, industry, federal state and time fixed effects are included. Baseline refers to the estimation of Equation (5.1) with the changes highlighted in the respective heading of each panel. Low indicates that the firm is related to a bank in the lower 25% of the variable's distribution of all German banks in the Bankscope data set. Cluster-robust standard errors in parentheses, clustered at the firm level. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

5.7.5 Model and dependent variable

Table 5.15: Model and dependent variable

	(1)	(2)	(3)	(4)	(5)
	Baseline	Tangible common equity		Capital funds	
		Low	High	Low	High
Panel A: Homoscedastic Tobit					
Rating	−0.013***	−0.013***	−0.012*	−0.012**	−0.012*
	(0.004)	(0.005)	(0.007)	(0.005)	(0.006)
Rating × Crisis	−0.012***	−0.013**	−0.011	−0.015***	−0.009
	(0.005)	(0.005)	(0.009)	(0.006)	(0.007)
Rating × PostCrisis	0.000	0.001	−0.007	−0.001	−0.003
	(0.005)	(0.006)	(0.009)	(0.006)	(0.007)
Constant	7.612***	8.114***	6.727***	7.455***	6.837***
	(1.187)	(1.453)	(2.190)	(1.504)	(1.909)
Observations	8739	6355	2384	5215	3254
Panel B: OLS					
Rating	−0.012***	−0.011***	−0.011**	−0.011***	−0.010**
	(0.003)	(0.004)	(0.005)	(0.004)	(0.004)
Rating × Crisis	−0.008**	−0.009**	−0.007	−0.011**	−0.005
	(0.003)	(0.004)	(0.006)	(0.004)	(0.005)
Rating × PostCrisis	0.000	0.001	−0.005	−0.001	−0.003
	(0.004)	(0.004)	(0.007)	(0.005)	(0.005)
Constant	8.888***	9.240***	8.305***	8.737***	8.321***
	(0.891)	(1.112)	(1.581)	(1.169)	(1.360)
Observations	8739	6355	2384	5215	3254
Panel C: Heteroscedastic Tobit with scaled dependent variable					
Rating	−0.003	−0.002	−0.006	−0.002	−0.003
	(0.002)	(0.003)	(0.004)	(0.003)	(0.004)
Rating x Crisis	−0.009***	−0.011***	−0.007	−0.011***	−0.005
	(0.003)	(0.003)	(0.005)	(0.004)	(0.005)
Rating x PostCrisis	−0.004	−0.004	−0.004	−0.003	−0.004
	(0.003)	(0.003)	(0.006)	(0.004)	(0.005)
Constant	4.005***	4.009***	4.557***	3.967***	4.052***
	(0.882)	(1.149)	(1.482)	(1.171)	(1.370)
Observations	8713	6334	2379	5199	3514

Notes: All estimations include firm controls as described in Section 5.3.1. Moreover, industry, federal state and time fixed effects are included. Baseline refers to the estimation of Equation (5.1) with the changes highlighted in the respective heading of each panel. Low indicates that the firm is related to a bank in the lower 25% of the variable's distribution of all German banks in the Bankscope data set. Cluster-robust standard errors in parentheses, clustered at the firm level. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

Table 5.16: Changes to the heteroscedasticity term

	(1) Baseline	(2) Tangible common equity	(3)	(4) Capital funds	(5)
		Low	High	Low	High
Panel A: Baseline – Three size dummies, two age dummies, industry dummies					
Rating	−0.011***	−0.011***	−0.014**	−0.012***	−0.010*
	(0.003)	(0.004)	(0.007)	(0.004)	(0.005)
Rating × Crisis	−0.013***	−0.015***	−0.008	−0.017***	−0.005
	(0.004)	(0.005)	(0.008)	(0.005)	(0.007)
Rating × PostCrisis	−0.004	−0.004	−0.008	−0.002	−0.008
	(0.004)	(0.005)	(0.009)	(0.005)	(0.007)
Constant	6.743***	6.769***	6.773***	6.856***	6.123***
	(1.398)	(1.790)	(2.446)	(1.843)	(2.181)
Observations	8739	6355	2384	5215	3254
Panel B: Three size dummies, two age dummies					
Rating	−0.013***	−0.012***	−0.013*	−0.011**	−0.011*
	(0.004)	(0.004)	(0.007)	(0.005)	(0.006)
Rating × Crisis	−0.011**	−0.012**	−0.012	−0.014**	−0.008
	(0.005)	(0.005)	(0.008)	(0.006)	(0.007)
Rating × PostCrisis	−0.001	0.000	−0.008	−0.002	−0.005
	(0.005)	(0.006)	(0.009)	(0.006)	(0.007)
Constant	7.546***	8.177***	6.872***	7.501***	6.597***
	(1.183)	(1.453)	(2.183)	(1.511)	(1.916)
Observations	8739	6355	2384	5215	3254
Panel C: Only industry dummies					
Rating	−0.012***	−0.011***	−0.013*	−0.012***	−0.010*
	(0.003)	(0.004)	(0.007)	(0.004)	(0.005)
Rating × Crisis	−0.012***	−0.016***	−0.007	−0.017***	−0.006
	(0.004)	(0.005)	(0.008)	(0.005)	(0.007)
Rating × PostCrisis	−0.003	−0.003	−0.007	−0.002	−0.007
	(0.004)	(0.005)	(0.009)	(0.005)	(0.007)
Constant	6.865***	6.763***	6.742***	6.870***	6.185***
	(1.397)	(1.784)	(2.492)	(1.821)	(2.189)
Observations	8739	6355	2384	5215	3254
Panel D: Baseline variables and Group, Sales growth, Export share					
Rating	−0.011***	−0.011***	−0.013**	−0.012***	−0.009*
	(0.003)	(0.004)	(0.006)	(0.004)	(0.005)
Rating × Crisis	−0.012***	−0.013***	−0.010	−0.016***	−0.003
	(0.004)	(0.005)	(0.008)	(0.005)	(0.007)
Rating × PostCrisis	−0.004	−0.005	−0.006	−0.003	−0.007
	(0.004)	(0.005)	(0.009)	(0.005)	(0.007)
Constant	6.735***	6.599***	6.818***	6.796***	5.977***
	(1.371)	(1.813)	(2.354)	(1.872)	(2.058)
Observations	8739	6355	2384	5215	3254

Notes: All estimations include firm controls as described in Section 5.3.1. Moreover, industry, federal state and time fixed effects are included. Baseline refers to the estimation of Equation (5.1) with the changes highlighted in the respective heading of each panel. Low indicates that the firm is related to a bank in the lower 25% of the variable's distribution of all German banks in the Bankscope data set. Cluster-robust standard errors in parentheses, clustered at the firm level. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

5.7.6 Changes to the rating variable

Table 5.17: Changes of the rating variable

	(1)	(2)	(3)	(4)	(5)
	Baseline	Tangible common equity		Capital funds	
		Low	High	Low	High
Panel A: Lagged rating index					
Rating	−0.011***	−0.010***	−0.013**	−0.012***	−0.008
	(0.003)	(0.004)	(0.006)	(0.004)	(0.005)
Rating × Crisis	−0.010**	−0.012**	−0.005	−0.014***	−0.002
	(0.004)	(0.005)	(0.008)	(0.005)	(0.007)
Rating × PostCrisis	−0.004	−0.003	−0.010	−0.001	−0.010
	(0.004)	(0.005)	(0.009)	(0.005)	(0.007)
Constant	6.629***	6.659***	6.677***	6.905***	5.581***
	(1.367)	(1.773)	(2.359)	(1.808)	(2.144)
Observations	8739	6355	2384	5215	3254
Panel B: Mean of rating over the period 2004 to 2006					
Rating	−0.013***	−0.011**	−0.022***	−0.012**	−0.014**
	(0.004)	(0.004)	(0.008)	(0.005)	(0.006)
Rating × Crisis	−0.017***	−0.018***	−0.014	−0.016***	−0.017**
	(0.005)	(0.005)	(0.009)	(0.006)	(0.008)
Rating × PostCrisis	−0.005	−0.007	−0.001	−0.004	−0.009
	(0.005)	(0.006)	(0.011)	(0.006)	(0.008)
Constant	7.371***	7.195***	8.683***	7.104***	7.201***
	(1.496)	(1.873)	(2.742)	(1.968)	(2.328)
Observations	7564	5540	2024	4598	2966
Panel C: Adding observations with ratings equal or above 500					
Rating	−0.007***	−0.005**	−0.015**	−0.005*	−0.012***
	(0.002)	(0.002)	(0.007)	(0.003)	(0.004)
Rating × Crisis	−0.011**	−0.012**	−0.009	−0.013**	−0.005
	(0.004)	(0.005)	(0.007)	(0.006)	(0.006)
Rating × PostCrisis	−0.005	−0.007*	0.002	−0.008*	0.001
	(0.004)	(0.004)	(0.010)	(0.005)	(0.007)
Constant	5.741***	5.660***	6.962***	5.444***	6.510***
	(1.293)	(1.661)	(2.422)	(1.690)	(2.053)
Observations	8806	6405	2401	5263	3543

Notes: All estimations include firm controls as described in Section 5.3.1. Moreover, industry, federal state and time fixed effects are included. Baseline refers to the estimation of Equation (5.1) with the changes highlighted in the respective heading of each panel. Low indicates that the firm is related to a bank in the lower 25% of the variable's distribution of all German banks in the Bankscope data set. Cluster-robust standard errors in parentheses, clustered at the firm level. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

5.7.7 Changes concerning bank related information

Table 5.18: Changes concerning bank related information

	(1)	(2)	(3)	(4)	(5)
	Baseline	Tangible common equity		Capital funds	
		Low	High	Low	High
Panel A: Cut point for bank variables at 10%					
Rating	−0.011***	−0.008**	−0.013**	−0.011*	−0.011**
	(0.003)	(0.004)	(0.006)	(0.006)	(0.004)
Rating × Crisis	−0.013***	−0.015***	−0.009	−0.017**	−0.011**
	(0.004)	(0.005)	(0.007)	(0.007)	(0.005)
Rating × PostCrisis	−0.004	−0.005	−0.010	−0.005	−0.007
	(0.004)	(0.005)	(0.008)	(0.008)	(0.005)
Constant	6.743***	6.689***	6.279***	7.411***	5.839***
	(1.398)	(1.877)	(2.310)	(2.624)	(1.613)
Observations	8739	5432	3307	2409	6330
Panel B: Cut point for bank variables at 50%					
Rating	−0.011***	−0.011***	−0.016*	−0.013***	−0.007
	(0.003)	(0.004)	(0.009)	(0.004)	(0.007)
Rating × Crisis	−0.013***	−0.015***	−0.001	−0.015***	−0.002
	(0.004)	(0.005)	(0.011)	(0.005)	(0.009)
Rating × PostCrisis	−0.004	−0.005	−0.007	−0.003	−0.006
	(0.004)	(0.005)	(0.015)	(0.005)	(0.009)
Constant	6.743***	6.253***	9.206***	7.059***	4.768*
	(1.398)	(1.596)	(3.137)	(1.587)	(2.697)
Observations	8739	7615	1124	2400	6339
Panel C: Without bank switching firms					
Rating	−0.012***	−0.011**	−0.016	−0.015***	−0.005
	(0.005)	(0.005)	(0.011)	(0.005)	(0.008)
Rating × Crisis	−0.014**	−0.019***	0.006	−0.019***	−0.006
	(0.005)	(0.006)	(0.012)	(0.006)	(0.010)
Rating × PostCrisis	−0.005	−0.004	−0.005	0.001	−0.011
	(0.006)	(0.006)	(0.013)	(0.006)	(0.010)
Constant	7.443***	8.316***	5.900*	9.425***	3.678
	(1.687)	(2.020)	(3.421)	(2.006)	(2.946)
Observations	5765	4212	1553	3468	2297

Notes: All estimations include firm controls as described in Section 5.3.1. Moreover, industry, federal state and time fixed effects are included. Baseline refers to the estimation of Equation (5.1) with the changes highlighted in the respective heading of each panel. Low indicates that the firm is related to a bank in the lower 10% (Panel A), 25% (Panel C) or 50% (Panel B) of the variable's distribution of all German banks in the Bankscope data set. Cluster-robust standard errors in parentheses, clustered at the firm level. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

Table 5.19: Results based on different variables for bank capitalization

	(1)	(2)	(3)	(4)	(5)
	Baseline	Equity over total assets		Capital funds over net loans	
		Low	High	Low	High
Rating	−0.011***	−0.011***	−0.014**	−0.007	−0.012***
	(0.003)	(0.004)	(0.007)	(0.005)	(0.004)
Rating × Crisis	−0.013**	−0.016***	−0.007	−0.023***	−0.008
	(0.004)	(0.005)	(0.008)	(0.006)	(0.006)
Rating × PostCrisis	−0.004	−0.004	−0.008	−0.006	−0.007
	(0.004)	(0.005)	(0.009)	(0.007)	(0.006)
Constant	6.743***	6.698***	6.807***	6.728***	6.210***
	(1.398)	(1.772)	(2.472)	(2.048)	(1.783)
Observations	8739	6371	2368	3130	5609

Notes: All estimations include firm controls as described in Section 5.3.1. Moreover, industry, federal state and time fixed effects are included. Baseline refers to the estimation of Equation (5.1) with the changes highlighted in the respective heading of each panel. Low indicates that the firm is related to a bank in the lower 25% of the variable's distribution of all German banks in the Bankscope data set. Cluster-robust standard errors in parentheses, clustered at the firm level. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

5.7.8 Sample size and time period definition

Table 5.20: Changes to time period definition

	(1) Baseline	(2) Tangible common equity	(3)	(4) Capital funds	(5)
		Low	High	Low	High
Panel A: Differentiate Basel introduction and Crisis period					
Rating	−0.011***	−0.011***	−0.014**	−0.012***	−0.010*
	(0.003)	(0.004)	(0.007)	(0.004)	(0.005)
Rating × Basel	−0.017***	−0.020***	−0.016	−0.016**	−0.020**
	(0.006)	(0.007)	(0.011)	(0.007)	(0.009)
Rating × Crisis	−0.011**	−0.013**	−0.004	−0.017***	0.003
	(0.005)	(0.006)	(0.010)	(0.006)	(0.009)
Rating × PostCrisis	−0.004	−0.004	−0.008	−0.002	−0.008
	(0.004)	(0.005)	(0.009)	(0.005)	(0.007)
Constant	6.745***	6.772***	6.788***	6.855***	6.136***
	(1.396)	(1.788)	(2.447)	(1.843)	(2.181)
Observations	8739	6355	2384	5215	3254
Panel B: With pre-crisis downturn (2002 and 2003)					
Rating	−0.010***	−0.010**	−0.012*	−0.010**	−0.011*
	(0.004)	(0.004)	(0.007)	(0.005)	(0.006)
Rating × Early2000	−0.004	−0.002	−0.005	−0.004	0.003
	(0.005)	(0.006)	(0.011)	(0.007)	(0.008)
Rating × Crisis	−0.014***	−0.016***	−0.010	−0.018***	−0.004
	(0.005)	(0.006)	(0.008)	(0.006)	(0.007)
Rating × PostCrisis	−0.005	−0.004	−0.010	−0.003	−0.007
	(0.005)	(0.005)	(0.010)	(0.006)	(0.007)
Constant	7.288***	7.048***	7.662**	7.502***	5.602**
	(1.579)	(1.927)	(3.037)	(2.054)	(2.555)
Observations	8739	6355	2384	5215	3254

Notes: All estimations include firm controls as described in Section 5.3.1. Moreover, industry, federal state and time fixed effects are included. Baseline refers to the estimation of Equation (5.1) with the changes highlighted in the respective heading of each panel. Low indicates that the firm is related to a bank in the lower 25% of the variable's distribution of all German banks in the Bankscope data set. Cluster-robust standard errors in parentheses, clustered at the firm level. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

Table 5.21: Changes to sample size

	(1)	(2)	(3)	(4)	(5)
	Baseline	Tangible common equity		Capital funds	
		Low	High	Low	High
Panel A: Without the years 2002 and 2003					
Rating	−0.010***	−0.009**	−0.013*	−0.010**	−0.011*
	(0.004)	(0.004)	(0.007)	(0.005)	(0.006)
Rating × Crisis	−0.014***	−0.016***	−0.010	−0.017***	−0.005
	(0.005)	(0.006)	(0.008)	(0.006)	(0.007)
Rating × PostCrisis	−0.005	−0.004	−0.008	−0.003	−0.006
	(0.005)	(0.005)	(0.010)	(0.006)	(0.007)
Constant	7.103***	7.224***	7.432***	6.792***	7.500***
	(1.473)	(1.901)	(2.535)	(1.996)	(2.233)
Observations	7617	5504	2113	4483	3134
Panel B: Without the years 2002, 2003 and 2004					
Rating	−0.014***	−0.013**	−0.019**	−0.012**	−0.018***
	(0.005)	(0.005)	(0.008)	(0.006)	(0.007)
Rating × Crisis	−0.011**	−0.012**	−0.006	−0.016**	0.001
	(0.005)	(0.006)	(0.009)	(0.006)	(0.008)
Rating × PostCrisis	−0.002	−0.001	−0.004	−0.001	0.000
	(0.005)	(0.006)	(0.010)	(0.006)	(0.008)
Constant	7.818***	7.891***	8.681***	7.102***	8.779***
	(1.691)	(2.209)	(2.696)	(2.332)	(2.361)
Observations	6770	4876	1894	3960	2810

Notes: All estimations include firm controls as described in Section 5.3.1. Moreover, industry, federal state and time fixed effects are included. Baseline refers to the estimation of Equation (5.1) with the changes highlighted in the respective heading of each panel. Low indicates that the firm is related to a bank in the lower 25% of the variable's distribution of all German banks in the Bankscope data set. Cluster-robust standard errors in parentheses, clustered at the firm level. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

5.7.9 Selection in the subsidy recipient status and definition of the subsidy variable

Table 5.22: Matching results to obtain the propensity score for the construction of the inverse probability weights

	(1)
Dependent variable	Subsidy recipient
Rating	0.002
	(0.002)
Rating × 2003	0.000
	(0.002)
Rating × 2004	−0.003
	(0.002)
Rating × 2005	−0.003*
	(0.002)
Rating × 2006	−0.003
	(0.002)
Rating × 2007	−0.004*
	(0.002)
Rating × 2008	−0.004*
	(0.002)
Rating × 2009	−0.001
	(0.002)
Rating × 2010	−0.002
	(0.002)
Rating × 2011	−0.001
	(0.002)
Rating × 2012	−0.003
	(0.002)
Size	0.103***
	(0.036)
Size squared	0.000
	(0.002)
Age	−0.003
	(0.002)
Age squared	0.000
	(0.000)
Group	−0.086**
	(0.037)
Sales growth	0.243***
	(0.069)
Export share	0.005***
	(0.001)
Constant	−1.389***
	(0.358)
Log likelihood	-3584.029
Observations	6148

Notes: Each regression includes industry times federal state fixed effects. Standard errors in parentheses. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

Table 5.23: Mean comparison after matching – Means calculated using inverse probability weights

	Mean		Difference	p-value
Variable	Control	Treated		
Rating	216.013	214.711	−1.302	0.276
Rating × 2003	15.252	15.097	−0.155	0.925
Rating × 2004	20.381	20.425	0.044	0.982
Rating × 2005	22.634	23.064	0.430	0.835
Rating × 2006	23.733	23.888	0.156	0.940
Rating × 2007	24.534	24.294	−0.241	0.908
Rating × 2008	21.282	21.181	−0.101	0.960
Rating × 2009	17.980	17.612	−0.368	0.836
Rating × 2010	20.584	20.647	0.063	0.974
Rating × 2011	17.683	17.186	−0.497	0.776
Rating × 2012	16.680	16.610	−0.070	0.968
Size	0.238	0.233	−0.005	0.784
Size Squared	0.597	0.423	−0.174	0.354
Age	31.026	32.271	1.245	0.240
Age squared	1964.458	2088.867	124.410	0.364
Part of firm group	0.512	0.522	0.009	0.529
Sales growth	0.061	0.062	0.001	0.920
Export share	24.168	23.791	−0.377	0.621

Table 5.24: Re-weighted regressions for the impact of firm financing constraints on R&D accounting for yearly effects of subsidies

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable	Baseline	Control for Subsidies	Tangible common equity		Capital funds	
			Low	High	Low	High
Rating	−0.007*	−0.008**	−0.006	−0.011*	−0.009*	−0.006
	(0.004)	(0.004)	(0.005)	(0.006)	(0.005)	(0.006)
Rating × Crisis	−0.012**	−0.011**	−0.016***	−0.005	−0.011*	−0.011
	(0.005)	(0.005)	(0.006)	(0.007)	(0.006)	(0.007)
Rating × PostCrisis	−0.006	−0.007	−0.004	−0.013	−0.002	−0.006
	(0.006)	(0.006)	(0.007)	(0.011)	(0.008)	(0.009)
Constant	8.153***	6.413***	6.299***	6.560***	6.552***	6.053**
	(2.069)	(1.698)	(2.220)	(2.516)	(2.149)	(2.555)
H_0 : Rating × $\text{year}_t = 0 \ \forall \ t < 2007$						
p-value	0.220	0.311	0.404	0.472	0.737	0.472
H_0 : Subsidy × $\text{year}_t = 0 \ \forall \ t < 2007$						
p-value		0.863	0.861	0.962	0.968	0.923
Firm controls	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Federal state fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Log Likelihood	-33561.315	-32744.664	-24106.882	-8457.516	-19897.433	-12583.397
Left-censored observations	1634	1634	1136	498	889	745
Uncensored observations	4480	4480	3340	1140	2808	1672
Observations	6114	6114	4476	1638	3697	2417

Notes: All estimations include firm controls as described in Section 5.3.1. Moreover, industry, federal state and time fixed effects are included. Baseline refers to the estimation of Equation (5.1) with the changes highlighted in the respective heading of each panel. Low indicates that the firm is related to a bank in the lower 25% of the variable's distribution of all German banks in the Bankscope data set. Columns (2) to (6) include a subsidy dummy and subsidy times year interactions. Subsidy indicates that the firm is a subsidy recipient. Cluster-robust standard errors in parentheses, clustered at the firm level. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

Table 5.25: Re-weighted regressions for the impact of firm financing constraints on R&D accounting for subsidies and bank differences

Dependent variable	(1)	(2)	(3)	(4)	(5)	(6)
	Baseline		Low Tangible common equity		Low Capital funds	
	Subsidy	No-subsidy	Subsidy	No-subsidy	Subsidy	No-subsidy
Rating	−0.009***	−0.007	−0.011**	−0.005	−0.007	−0.007
	(0.003)	(0.007)	(0.005)	(0.008)	(0.005)	(0.009)
Rating × Crisis	−0.005	−0.021**	−0.007	−0.027***	0.001	−0.025**
	(0.004)	(0.008)	(0.005)	(0.010)	(0.004)	(0.011)
Rating × PostCrisis	0.000	−0.013	0.002	−0.007	−0.001	−0.007
	(0.006)	(0.011)	(0.006)	(0.013)	(0.006)	(0.014)
Constant	12.646***	1.917	13.035***	0.593	11.771***	0.807
	(1.539)	(2.599)	(2.323)	(3.383)	(2.018)	(3.561)
H_0 : Rating × $\text{year}_t = 0 \quad \forall \quad t < 2007$						
p-value	0.141	0.303	0.351	0.161	0.482	0.573
Firm controls	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Federal state fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Log Likelihood	-15780.284	-15340.924	-11620.987	-11166.833	-9092.266	-9215.519
Left-censored observations	170	1464	131	1005	92	797
Uncensored observations	2151	2329	1705	1635	1464	1344
Observations	2321	3793	1836	2640	1556	2141

Notes: All estimations include firm controls as described in Section 5.3.1. Moreover, industry, federal state and time fixed effects are included. Low indicates that the firm is related to a bank in the lower 25% of the variable's distribution of all German banks in the Bankscope data set. Subsidy indicates that the firm is a subsidy recipient. Cluster-robust standard errors in parentheses, clustered at the firm level. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

Table 5.26: Impact of firm financing constraints on R&D accounting for yearly effects of subsidies – Different subsidy definitions

Dependent variable	(1) Baseline	(2) Control for Subsidies	(3) Tangible common equity	(4)	(5) Capital funds	(6)
			Low	High	Low	High
Panel A: Received a subsidy in any time of the sample period (2002-2012)						
Rating	−0.012***	−0.011***	−0.011**	−0.007	−0.009*	−0.011*
	(0.004)	(0.004)	(0.005)	(0.007)	(0.005)	(0.006)
Rating × Crisis	−0.014***	−0.012**	−0.016***	−0.010	−0.015**	−0.010
	(0.005)	(0.005)	(0.006)	(0.009)	(0.006)	(0.008)
Rating × PostCrisis	−0.005	−0.007	−0.005	−0.015	−0.005	−0.008
	(0.006)	(0.006)	(0.007)	(0.012)	(0.007)	(0.009)
Constant	6.377***	5.324***	5.643***	3.438	5.115**	4.273
	(1.773)	(1.596)	(2.018)	(2.810)	(1.995)	(2.708)
Observations	6148	6148	4510	1638	3728	2420
Panel B: Received a subsidy in the pre-crisis period (2002-2006)						
Rating	−0.011***	−0.012***	−0.011**	−0.011	−0.011**	−0.012*
	(0.004)	(0.004)	(0.005)	(0.007)	(0.005)	(0.006)
Rating × Crisis	−0.018***	−0.015***	−0.020***	−0.009	−0.016**	−0.010
	(0.005)	(0.005)	(0.006)	(0.009)	(0.007)	(0.008)
Rating × PostCrisis	−0.009	−0.010	−0.010	−0.007	−0.009	−0.003
	(0.006)	(0.006)	(0.007)	(0.013)	(0.008)	(0.010)
Constant	7.045***	6.568***	6.959***	4.468	7.080***	4.480
	(1.726)	(1.559)	(1.881)	(2.852)	(1.822)	(2.916)
Observations	5163	5163	3819	1344	3204	1959

Notes: All estimations include firm controls as described in Section 5.3.1. Moreover, industry, federal state and time fixed effects are included. Baseline refers to the estimation of Equation (5.1) with the changes highlighted in the respective heading of each panel. Low indicates that the firm is related to a bank in the lower 25% of the variable's distribution of all German banks in the Bankscope data set. Columns (2) to (6) include a subsidy dummy and subsidy times year interactions. Subsidy indicates that the firm is a subsidy recipient. Cluster-robust standard errors in parentheses, clustered at the firm level. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

Table 5.27: Impact of firm financing constraints on R&D accounting for subsidies and bank differences – Different subsidy definitions

Dependent variable	(1) Baseline	(2)	(3) Low Tangible common equity	(4)	(5) Low Capital funds	(6)
	Subsidy	No-subsidy	Subsidy	No-subsidy	Subsidy	No-subsidy
Panel A: Received a subsidy in any time of the sample period (2002-2012)						
Rating	−0.013***	−0.008	−0.017***	−0.007	−0.016***	−0.000
	(0.003)	(0.008)	(0.004)	(0.009)	(0.004)	(0.010)
Rating × Crisis	−0.003	−0.022**	−0.003	−0.030***	0.001	−0.028**
	(0.004)	(0.009)	(0.005)	(0.012)	(0.005)	(0.012)
Rating × PostCrisis	0.004	−0.016	0.007	−0.010	0.006	−0.011
	(0.005)	(0.011)	(0.005)	(0.014)	(0.005)	(0.015)
Constant	14.199***	1.694	15.495***	0.983	14.874***	−0.661
	(1.288)	(2.636)	(1.572)	(3.364)	(1.701)	(3.446)
Observations	2780	3368	2208	2302	1878	1850
Panel B: Received a subsidy in the pre-crisis period (2002-2006)						
Rating	−0.013***	−0.009	−0.016***	−0.010	−0.013***	−0.008
	(0.003)	(0.007)	(0.004)	(0.008)	(0.005)	(0.009)
Rating × Crisis	−0.002	−0.029***	−0.002	−0.038***	0.001	−0.032***
	(0.004)	(0.009)	(0.005)	(0.011)	(0.005)	(0.012)
Rating × PostCrisis	0.003	−0.027**	0.004	−0.027*	0.006	−0.038**
	(0.005)	(0.012)	(0.005)	(0.014)	(0.005)	(0.016)
Constant	13.916***	3.574	15.068***	3.848	13.281***	4.034
	(1.165)	(2.505)	(1.463)	(2.996)	(1.645)	(2.997)
Observations	1969	3194	1587	2232	1357	1847

Notes: All estimations include firm controls as described in Section 5.3.1. Moreover, industry, federal state and time fixed effects are included. Low indicates that the firm is related to a bank in the lower 25% of the variable's distribution of all German banks in the Bankscope data set. Subsidy indicates that the firm is a subsidy recipient. Cluster-robust standard errors in parentheses, clustered at the firm level. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

Chapter 6

Summary and Conclusion

6.1 Summary of the main findings

The aim of this thesis is to provide evidence for the impact of financial markets on innovation and innovative firms. This topic is of particular interest as the importance of external financing (e.g. bank financing) to innovation remains under discussion (e.g. Hall 2002; Kerr & Nanda 2015). To provide causal empirical evidence, the financial crisis is utilized as a negative, exogenous shock to banks. Especially in bank dependent economies like Germany's, the financial stresses on banks leads to adverse effects in the real sector. This is, among others, rooted in the reduction of credit supply by banks which are highly dependent on the interbank market or have a low capital base. Besides, limited substitution opportunities make it difficult for firms to source external financing from other channels than bank debt. Using this exogenous shock, the thesis provides causal evidence for the sensitivity of innovation to bank financing in general (Chapters 3, 4 and 5) and shows the impact of the financial crisis on capital investments in innovative firms (Chapter 2).

For innovation expenses and similarly for capital investments, the effect of a demand reduction in an economic downturn is expected to be negative[1] (e.g. Knudsen & Lien 2014; Schmookler 1966; Shleifer 1986) which is rooted in decreased investment opportunities.[2] The resulting pro-cyclical investment pattern is observed in particular under credit constraints (e.g. Aghion et al. 2012; López-Garcia et al. 2013; Ouyang 2011). In this regard it might be questioned whether the reduction of innovation activities and investment expenditures in a downturn like the recent financial crisis is caused by the negative shock to banks or by the reduction in demand. The empirical evidence and applied additional tests carried out in this thesis (Chapters 2, 3, 4 and 5) imply that it is indeed the shock to the bank system that drives the negative effects for firms. Nevertheless, the argument could not be dismissed that demand reduction plays a partial role.

In Chapter 2, capital investments are considered as they are central for economic growth and largely financed by external means. Thus, capital expenditures form a suitable indicator to determine the impact of the financial crisis dependent on firm determinants like innovativeness. Concerning capital investments, empirical studies have already found that investments were reduced during the crisis (Almeida et al. 2012; Campello et al. 2010; Duchin et al. 2010; Vermoesen et al. 2013) and that innovators suffered from worse access to external financing (e.g. Lee et al. 2015). However, no study has considered the impact of the financial crisis on capital investments in innovative firms. The results in Chapter 2 indicate that innovative firms clearly suffered from the financial crisis and invested less in capital goods as a result. This holds in particular for innovative firms which utilize external financing like bank loans. Further tests in the chapter reveal that this relation-

[1] See e.g. Aghion & Saint-Paul (1998); Barlevy (2007); Davis & Haltiwanger (1990); Stiglitz (1994) who argue that demand effects might affect innovation in firms positively due to an opportunity cost effect. According to Knudsen & Lien (2014), this positive effect only holds for moderate reductions in demand.

[2] See Knudsen and Lien (2014) for a discussion of the effects of a demand reduction on capital expenditures and investments in R&D.

ship is also true for different definitions of the innovator status and for the assumption that a specific size of external financing has to be obtained for a firm to be declared as an external financing user.

The insights in Chapter 2 additionally yield results regarding whether using equity financing mitigates a shock to the bank market. This is particularly interesting as the assumption could be made that firms try to move away from bank financing in times of stress in the bank system. The possible availability of additional sources of financing might mitigate bank financing constraints. Conversely, the results in Chapter 2 point towards difficulties in substituting financing sources in times of stress on the financial markets. Thus, it coincides with the findings of studies like Kahle & Stulz (2013) as well as Lemmon & Roberts (2010).

From a theoretical perspective, the influence of changes in bank lending on innovation is related to the question of whether it would be better for firms to take on costly debt than to rebuild a scrutinized R&D department (Knudsen & Lien 2014).[3] Taking this consideration into account, it remains debatable if and how firms adjust their innovation expenditures in times of scarce bank financing. With respect to the 'if' component of this question, studies so far have used regional indicators (e.g. changes in the bank system) to determine a relation between finance and innovation (e.g. Alessandrini et al. 2010; Amore et al. 2013; Benfratello et al. 2008; Chava et al. 2013; Cornaggia et al. 2015; Hsu et al. 2014; Nanda & Nicholas 2014). Thus, it might be argued that the effect of bank financing on innovation remains open to some extent. Concerning the 'how' component, Nanda & Nicholas (2014) for instance find that firms in areas that experienced higher bank distress in the Great Depression pursued more conservative projects as a result. Moreover, studies like Czarnitzki et al. (2010) show that the research component of R&D expenses reacts more sensitively to firms operating liquidity. This leaves room for the assumption that a negative bank credit supply shock affects innovation expenses and that the effect might be heterogeneous for its components.

Using detailed firm-bank level data and the shock to the interbank market as an identification of external financing constraints, Chapter 3 sheds light on the question of whether and how innovation expenses react to a negative shock to bank financing. First, the results in Chapter 3 show that innovation expenses are affected negatively by external financing constraints of firms. Second, the results reveal that the flexible part (investments in innovation projects) reacts to some extent more sensitively to external financing constraints than the inflexible part (current innovation expenses, e.g. personnel). Consequently, the theoretical argument that characteristics of innovation expenses mean that they are not sensitive to external financing might not hold. It could be argued that the effect depends on the relative size of the inflexible part of the expenses.

[3]See also Robison et al. (1987) who show that firms prefer taking on bank debt to survive in times of financial distress.

In addition to considering various innovation measures Chapter 3 also yields results for marketing expenses. Empirical studies show that marketing expenditures are, among others, related to a firm's systematic risk (McAlister et al. 2007), leverage (Malshe & Agarwal 2015) and financial health (Fischer & Himme 2017; Singh et al. 2005). However, it remains unclear to some extent how financial strength affects advertising expenditures. In that respect, Campello et al. (2010) found a negative effect for firms affected by the financial crisis on marketing expenditures. Similarly, the results in Chapter 3 show that marketing expenditures are negatively affected by the external financing constraints of firms. This hints at a reaction of marketing expenditures to external financing constraints. Nevertheless, further research on this topic is needed.

Besides the impact on innovation input it remains open to discussion how firms adjusted their innovation behavior in the financial crisis. Short term adjustments might be suitable to forego temporary financial constraints by reallocating financial resources to other firm divisions without making irreversible changes to the innovation department. Long term adjustments (e.g. changing the innovation strategy), however, might incur large costs and large irreversibility. Even if empirical works have found an impact of the financial crisis on innovation (e.g. Archibugi et al. 2013a; Archibugi et al. 2013b; Filippetti & Archibugi 2011; Paunov 2012), external financing has been largely neglected. Moreover, these studies focus on R&D expenditures or halted innovation projects, which have limited information content with respect to the detailed changes which occur in the innovation department.[4] Additionally, studies (e.g. Balduzzi et al. 2018; Bentolila et al. 2017; Chodorow-Reich 2014; Cingano et al. 2016; Dwenger et al. 2018; Iyer et al. 2014; Popov & Rocholl 2018) which analyze the impact of the credit supply channel in the financial crisis on firm outcomes have neglected innovation. Thus, it becomes clear that examining the bank credit supply channel for detailed innovation changes in the financial crisis is important to generate further information on firm behavior in times of stress on financial markets.

The empirical results of Chapter 4 show that the negative credit supply shock of the financial crisis largely affected the innovation behavior of firms. In that respect the chapter shows that firms adjusted their innovation activities in 2009 dependent on the credit supply during the financial crisis. These activities comprise of the reduction of innovation activities due to funding shortages, the initiation of additional innovation activities and the reallocation of labor to a firm's innovation department. Thus, the results imply that the reallocation of resources (money and labor) towards innovation takes place when enough external financing is at hand. On the opposite side, the results in Chapter 4 imply that firms tended not to adjust their innovation strategy to cope with the crisis. This is particularly interesting as the innovation strategy is essential for firm growth and survival (e.g. Guan et al. 2009). Thus, credit supply restrictions led to short term adjustments but no change in the long-term strategy of firms. This finding fits the theoretical argument

[4]See He & Tian (2018) for a discussion of the appropriateness of R&D and patents to reflect changes in firm financing of innovation.

that the readjustment of the R&D department requires high costs so that firms tend to choose moderate acts of innovation adjustment in times of scarce financial resources.

Chapters 3 and 4 show that innovation activities react sensitively to external financing. This seems to stand in contrast to the argument that the characteristics of innovation implies that they are predominantly financed by internal means (Bougheas et al. 2003; Hall 2002; Knudsen & Lien 2014). In that respect, the results in Chapter 4 reveal that short term innovation reduction due to funding shortages are dependent on external financing if the firm faces a reduction in internal means. For firms which do not experience changes to internal financing, no sensitivity of innovation reductions to external financing is found. This is in line with the proposition by Holmstrom & Tirole (1997) that poorly capitalized firms are hit hardest by shocks to bank credit. Thus, the results in Chapter 4 clearly point towards an important role of internal financing for innovation but also imply that the role of external financing is not negligible. Moreover, Chapter 4 in particular contributes to the finding (e.g. Aghion et al. 2012) that innovation investment is indeed pro-cyclical if firms face a reduction in internal means and bank financing constraints.

The direct impact of internal financing on R&D expenditures itself has already been investigated to a large extent by analyzing R&D to cash-flow sensitivities (e.g. Bond et al. 2005; Harhoff 1998; Himmelberg & Petersen 1994). Nevertheless, cash flow remains questionable as an indicator for firm financing constraints (Carreira & Silva 2010; Kaplan & Zingales 1997; Kaplan & Zingales 2000). As not only internal but also external financing is relevant for firms, studies have investigated whether the sensitivity of cash-flow changes with access to external financing in terms of equity (Brown et al. 2009; Brown et al. 2012; Brown et al. 2013; Brown & Petersen 2009; Brown & Petersen 2011). Thus, the investigation of this sensitivity, conditional on the access to bank financing, remains an open question in the literature (e.g. Brown et al. 2012; Kerr & Nanda 2015).

Chapter 5 fills this gap and takes another perspective on the relation between internal financing, external financing and R&D. A firm's credit rating is utilized as an indicator for firm financing constraints so as to determine whether a firm's constraints-R&D sensitivity depends on the situation in the financial markets. The results indicate that firms were indeed reacting more sensitively to financing constraints during the financial crisis. However, the effect is not persistent in the period right after. Furthermore, Chapter 5 determines that firm financing constraints are indeed more prevalent when the firm is associated with a bank which has larger problems in maintaining its credit supply in such a crisis (i.e. with a low capitalized bank). For firms which are related to a high capitalized bank, the intensity of firm financing constraints for R&D does not change over time. This again hints at the argument that external financing plays a role for innovation. Chapter 5 shows that, in particular, worse access to external financing results in stronger effects of firm financing constraints. Better access to external financing on the opposite mitigates the constraints problem to some extent.

In addition to the consideration of firm and bank financing constraints, Chapter 5 also includes an analysis of the effect of subsidies. This is particularly relevant as subsidies are an important sources of financing for R&D (e.g. Almus & Czarnitzki 2003; Becker 2015; Brautzsch et al. 2015; Howell 2017; Hud & Hussinger 2015; Zúñiga-Vicente et al. 2014) and might mitigate financing constraints (e.g. Hall et al. 2016; Hyytinen & Toivanen 2005; Takalo & Tanayama 2010). In that respect, the results of Chapter 5 show that receiving a subsidy does not strongly affect the impact of constraints when controlling for the receipt of subsidies. However, the subsidy itself affected the R&D expenditures of firms positively in the crisis period. A second set of tests imply that subsidies mitigate the financing constraints of firms and banks. Thus, firms which received a subsidy show no enhanced sensitivity to financing constraints of firms and banks in the financial crisis period. These results are also robust across several tests (e.g. changing the subsidy measure, accounting for selectivity).

6.2 Concluding remarks - Bank, firm and policy implications

As outlined in the introduction, R&D investments and innovation are a major contributing factor for economic growth. This is particularly important in an economic downturn like the recent financial crisis. Empirical studies show that firm innovation in the financial crisis indeed affected firm survival positively (e.g. Jung et al. 2018; Martinez et al. 2018). Moreover, it has been argued that technology is the key to economic recovery after a financial crisis (Storm & Naastepad 2015). As bank financing is determined as an important financing channel of innovation behavior, the results in this thesis yield important insights for banks, firms and policy makers.

It is known that bank capital is important for banks' resilience to shocks, liquidity creation, risk taking, competitiveness and governance (e.g. Diamond & Rajan 2000; Santos 2001). In that respect the regulation of bank capital has been debated for some time with mixed results both in favor and against it (e.g. Santos 2001; Thakor 2014). This is mainly rooted in the fact that the positive effects of a higher capital buffer (i.e. a buffer for shocks) must be traded off against the potential negative effects (i.e. lower liquidity creation) (Diamond & Rajan 2000). Most prominently the Basel accords (I, IA, II, III) were put in place and which propose minimum capital requirements and other mechanisms to put capital standards for banks in place (Santos 2001).

The recent financial crisis has led to an increased attention to bank capital regulations (Adrian et al. 2018; Repullo & Suarez 2012; Thakor 2014). It is shown in various empirical works that better capitalized banks were more stable (e.g. Berger & Bouwman 2013) and transmitted crisis effects to a lesser extent to the real sector (e.g. Kapan & Minoiu 2018;

Chapter 5 of this thesis). However, works like Thakor (2014) and Adrian et al. (2018) argue that the extent of bank capital regulation remains under discussion. In that respect Repullo & Suarez (2012) find that the risk base of the Basel II guidelines dominates Basel I in terms of welfare and they argue that Basel III might work even better due to its focus on capital quality. However, more evidence is needed to show whether the actual state of bank capital regulation development exerts positive effects and how future reforms should be designed.

The disruptions to the interbank market in the recent financial crisis led to a reduction in bank lending which had adverse effects on the real sector (e.g. Cingano et al. 2016; Iyer et al. 2014; Chapters 3 and 4 of this thesis). As asymmetric information in the bank system was a large issue during this time period, potential measures might aim to increase trust among banks. Even if certification or information systems (i.e. signaling and screening) might be possible ways to overcome this issue, costs and benefits have to be traded off against each other. Additionally, it might be a valuable policy to implement precautionary measures so that banks hold enough liquidity (Cingano et al. 2016). Thus, banks which use interbank market funding to a large extent are more prone to stresses on the financial system (e.g. Cornett et al. 2011). In that respect, Kapan & Minoiu (2018) show that a certain level of bank capital can serve as a mitigating factor for the credit supply frictions of banks due to shocks to wholesale funding. Measures with respect to capital size and quality have already been implemented in the Basel III guidelines. Although central bank capital injections are another option for maintaining bank credit supply, it remains to some extend questionable whether money from central banks can mitigate problems of liquidity distribution on financial markets (Iyer et al. 2014).

Another option to overcome liquidity problems due to stresses on wholesale funding markets are policy programs with specific targets. For example, in the United Kingdom, banks can obtain certain collateral (i.e. public debt) if they increase loan supply to SMEs (Iyer et al. 2014). This is particularly helpful for maintaining credit supply to SMEs as they face large difficulties in accessing external financing (e.g. Beck & Demirguc-Kunt 2006; Beck et al. 2008; Carbo-Valverde et al. 2016). Similarly, in Germany the Financial Market Stabilization Fund (Sonderfonds Finanzmarktstabilisierung - SoFFin)[5] was introduced in late 2008 to stabilize the financial system. One aim, among others, was to provide liquidity for banks. Support from the SoFFin for banks is explicitly based on the requirement that the funded banks supply sufficient loans to SMEs (Pleister 2011). Nevertheless, the functioning of the SoFFin remains to some extent questionable, as the study by Huber (2018) shows that Commerzbank related firms suffered particularly strongly from the financial crisis. Thus, central bank and government mechanism that aim to increase the supply of credit from banks to firms have to be well designed to exert positive effects.

[5]The SoFFin is operated by the Federal Agency for Financial Market Stabilization, which is supervised by the German Ministry of Finance. For more details see Pleister (2011).

As firms not only use bank financing, the strengthening of other financing sources is also an implication which can be drawn from this thesis. On the one hand this would be advantageous for firms as they would have more opportunities to find substitutes in times of scarce bank financing, when the banks are under financial pressure. On the other hand, strengthening the access to other financing sources might increase the substitution options for firms in normal times. As shown in the literature on bank competition, lenders might be able to obtain financing at lower costs due to higher competition between potential funders (e.g. Berger et al. 2001; Chong et al. 2013; Rice & Strahan 2010).

It has already shown that subsidies are important for innovation (Almus & Czarnitzki 2003; Becker 2015; Bronzini & Piselli 2016; Clausen 2009; Czarnitzki & Lopes-Bento 2013; Lach 2002; Chapter 5 of this thesis) as they, for example, help mitigate financing constraints (Takalo and Tanayama 2010; Chapter 5 of this thesis). In the financial crisis, it was shown that firms which were subsidized suffered less with respect to their innovation related expenses (e.g. Brautzsch et al. 2015; Hud & Hussinger 2015, Chapter 5 of this thesis). Consequently, the counter-cyclical subsidization of R&D and innovation might be a helpful policy measure in economic downturns. However, attention must be paid with respect to a potential crowding-out effect of subsidies for R&D expenditures (Hud & Hussinger 2015). To overcome the problem related to the question of whether subsidies crowd out R&D expenditures, targeted subsidy programs might be an alternative approach (Hottenrott & Lopes-Bento 2014). In times of exogenous shocks to the financial system, subsidy programs might be an effective policy instrument to attenuate the consequences of reductions in internal and external financing.

Another financing option for young enterprises is venture capital (VC). This is particularly helpful as young firms and start-ups face particularly strong problems in accessing external financing like bank loans (e.g. Hyytinen & Pajarinen 2007). Empirical studies have found that VC is positively associated with innovation (e.g. He & Tian 2018; Kortum & Lerner 2001). Even if this is the case, sourcing VC is not frequently undertaken in Germany (Schweer & Sahl 2017). Thus, policies should generally aim at strengthening venture capital funding for start-ups and young firms. As these firms also suffered particularly strongly in the financial crisis, this source of funding might also be important in times of stress in the banking system.

In addition, the results of this thesis have direct implications for firm policy. First, firms might choose their main bank with caution. Banks which are refinancing themselves to a high extent on the interbank market are beneficial in normal periods but not in times when financial markets are under stress. The opposite could be stated for highly capitalized banks. This also leads to another question brought up indirectly by Myers (1977): Should a firm borrow and if yes, how much? Thus, the management of financing is important, and the manager should choose banks and other financiers strategically. The strategic choice of which bank and what amount should guarantee that the financing mix is a suitable

balance to maintain a firm's survival and growth – especially in times of stress in the financial markets. Besides these managerial implications, taxation is another important point. On the one hand it has been shown that tax policies affect firm innovation (Hall & van Reenen 2000). Moreover, taxation exerts an impact on firms' financing decisions (MacKie-Mason 1990). Thus, taxation policies could be designed to support firms in times of stress on the financial markets.

The implications described above for banks, firms and policy makers might be helpful in attaining stable innovation financing. Active policy programs like the Europe 2020 program aim to foster growth by strengthening access to financing sources like debt and equity (e.g. European Commission 2010a; European Commission 2010b).[6] Similar to the Europe 2020 program, the Horizon 2020 policy program also comprises promoting the strengthening of access to financing sources to foster innovation (e.g. CSES 2017; European Commission 2011). For this purpose, the InnovFin program was first set-up as a reaction to the crisis induced stagnation in innovation and innovation financing (CSES 2017). This program aims to strengthen access to risk finance in terms of debt and equity (CSES 2017). Following this initiative, the European Fund for Strategic Investments (EFSI) was introduced to foster private financing for innovation (CSES 2017).

Even if it is argued that the Horizon 2020 program increased access to debt financing (CSES 2017), the Europe 2020 programs target of spending 3% of GDP on R&D has not yet been achieved (European Commission 2017; Eurostat 2018). This might imply that, on the one hand, further improvements for innovation financing are needed. On the other hand, there are likely to be other factors which seriously hamper the innovation behavior of firms. The experiences of the Horizon 2020 program are taken up in the Horizon Europe program which is the former's successor. Additionally, the innovation policy in Europe follows recent developments in the policy design for innovation which include mission-oriented funding (e.g. Mazzucato & Kattel 2018). Thus, the Horizon Europe program aims to strengthen innovation in the European Union from 2021 to 2027 by utilizing a mission-oriented policy approach (European Commission 2018; Mazzucato 2018). Future research evaluating this program will show whether these mission-oriented policies constitute a successful policy instrument.

[6]Similar targets (e.g. strengthening access to external financing (i.e. debt and equity) and R&D expenditures of 3% of GDP) are declared in the Horizon 2020 program (European Commission 2011).

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