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Bank Credit Supply and Firm Innovation

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Bank credit supply and firm innovation

Marek Giebel[a] and Kornelius Kraft[b]

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Abstract

We analyze the causal effect of the credit supply shock to banks induced by interbank market disruptions in the recent financial crisis 2008/2009 on their business customers' innovation activity. Using a matched bank-firm data set for Germany, we find that having relations with a more severely affected bank seriously hampers firms' current innovation activities due to funding shortages. Furthermore, we find that firms with a relationship to a less severely affected bank are more likely to initiate new product and process innovations and to reallocate human resources to innovation during the financial crisis.

JEL Classification: G01, G21, G30, O16, O30, O31

Keywords: Financing of innovations, credit supply, financial crisis, innovative activities

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1. Introduction

It is generally acknowledged that financial constraints are one of the main obstacles to innovation activity (e.g. Eurostat 2008), which in turn is an important driver for the growth of an economy (e.g. Solow 1956). The negative shock to the banking system as a result of the 2008/2009 crisis also affected the innovation activity of firms due to a liquidity shortage in the financial system (OECD 2012). The impact of the financial crisis 2008/2009 on financial markets has been widely discussed and is most prominently expressed by the reduction in bank lending (e.g. Ivashina and Scharfstein 2010, Iyer et al. 2014). The consequences of the reduced supply of external finance have been investigated, for example, with respect to changes in labor demand (e.g. Chodorow-Reich 2013) and investment activities (e.g. Cingano et al. 2016; Vermoesen et al. 2013). However, empirical investigations concerning the impact of individual banks affected by the financial crisis 2008/2009 on the innovation activity of their corporate customers do not yet exist. The aim of this paper is to investigate the effect of individual main bank changes in credit supply due to refinancing problems during the financial crisis on their corporate customers' innovation activity. Innovative activity is thereby separated into current innovation activities, the initiation of future innovation activities and reallocation of human resources to innovation.

In order to exploit the channel from bank lending constraints to firm innovation activity, we use an instrumental variable approach. Our identification strategy is based on the exogenous 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.

Our data basis is the Mannheim Innovation Panel (MIP), which provides information on firms including basic characteristics like size and turnover but also information regarding innovation activity. We also have data on the main bank related to the firms. To exploit this information, we link the information on firms to bank balance sheet information from Bankscope, compiled by

Bureau van Dijk. Our matched dataset allows for investigating the question as to how bank lending affected the innovative activity during the crisis.

Using a direct measure for the effect of the crisis on a bank's refinancing capabilities, we are able to identify the effect for lending capacities and then investigate how bank credit supply affected corporate innovation during the financial crisis. Accordingly, 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. What is more, we were able to show that those business customers with relations to a bank with higher credit growth are more likely to initiate additional innovation activities during the crisis. Moreover, we are able to show that firms related to a less affected bank are more likely to reallocate human resources to innovation in the crisis.

Applying this approach, we contribute to several strands of literature. First, we complement the literature that investigates innovation behavior of firms during the financial crisis (e.g. Amore 2015; Archibugi et al. 2013a & 2013b; Campello et al. 2010; Filippetti and Archibugi 2011). These studies focus on several firm characteristics but not explicitly on financing. Moreover, we contribute to the strand of literature that considers financing during the financial crisis (e.g. Paunov 2012). We complement this by considering external financing in terms of bank lending in detail. Moreover, we contribute to the strand of literature that investigates the impact of changes in the bank system on 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 and Nicholas 2014). We add to their strand of literature by investigating the effects during the financial crisis. Finally, we extend this strand of literature by directly investigating the effect of changes to the financial system when exploiting the data on firm-bank relations.

The remainder of the paper is structured as follows. The second section covers a description of the literature and channels how the financial crisis affects the innovation activity of firms. The third section covers a description of the data and variables, as well as methodology. The results are described in section four. The fifth and last section concludes.

2. Bank financing and innovation

2.1 Financing constraints and innovation

Besides constraints on internal financing, innovative firms in particular face serious problems accessing external financing. The external financing constraints originate in asymmetric information problems between borrower and lender (Hall 2002). These problems are mainly rooted in the uncertainties connected with the outcome of the R&D process and the success of the innovation on the market (Hall 2002; Hall and Lerner 2010). Moreover, returns and their variance are uncertain and make project evaluation difficult for capital suppliers (Magri et al. 2009). Additionally, an innovator is reluctant to provide a valuable signal to the lender for fear of imitation (Bhattacharya and Ritter 1983). This leads to significant problems for innovative firms attempting to access external capital, with the resulting financing constraints seriously hampering their innovation activities. Consequences observed in such situations include, for example, abandoned innovation projects or missed opportunities to initiate new projects.

Empirical studies support the theoretical findings of the relationship between financing problems and innovation activities.[1] Among others, the studies of Mohnen et al. (2008) and Savignac (2008) show that financial constraints generally hamper innovation activity. Besides this general approach, a strand of literature analyzes the relevance of internal financing by estimating the sensitivity of innovation to the availability of internal resources like cash flow.[2] Accordingly, studies find a positive effect of the availability of internal means on innovation activities (e.g. Benfratello et al. 2008; Canepa and Stoneman 2005; Parisi et al. 2006).

A complementing strand of empirical research shows that external financing is important for innovation activities. Utilizing a question on the degree of external finance usage Ayyagari (2011) shows that access to external financing facilitates innovation. Moreover, a number of studies consider the length of the firm-bank relationship (Giannetti 2012; Herrera and Minetti 2007) and find that long-lasting firm-bank relationships foster the introduction of innovation activities. In a similar direction, Giannetti (2012) shows that innovation intensity and the duration

[1] Empirical studies also investigate the impact of access to external financing on firms' R&D expenditure (Czarnitzki and Hottenrott 2011a & 2011b). They find that weaker access to external financing leads to lower R&D expenditure. Another strand of literature investigates the effect of credit constraints in economic downturns and shows that these lead to lower R&D expenditure (e.g. Aghion et al. 2012; Barlevy 2007; López-García 2013).

[2] Cash flow is a commonly applied measure to examine internal financial constraints on innovation inputs like R&D expenditure (e.g. Himmelberg and Petersen 1994; Bond et al. 2005).

of the firm-bank relationship are related. More indirect approaches to underline the relationship between changes in the banking system and innovation activates are used by 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 and Nicholas (2014). The general result is that innovative firms experience more problems accessing external finance than others (Freel 2007; Mina et al. 2013) and, therefore, there is a close correlation between the efficient operation of the banking sector and innovation input and output.

2.2 Impact of a negative bank shock on innovation financing

As most firms depend to some degree on bank loans[3] (e.g. Berger and Udell 1995; Boot 2000) a negative shock to bank lending will affect their financing decisions. This is rooted in the fact that, in all likelihood, a negative shock to banks will lead to higher borrowing costs and lower supply of bank credit (Kahle and Stulz 2013; Upper and Worms 2003). Moreover, firm financing is affected even if they try to substitute away from bank financing to other sources such as equity. This undertaking might not be successful, since these financing sources are also affected (Kahle and Stulz 2013) or because substitution is difficult (Holmstrom and Tirole 1997; Slovin 1993). Consequently, firms related to particularly hard-hit banks might experience greater difficulties accessing debts or be forced to accept worse borrowing conditions in order to obtain funding, and therefore suffer more severely as a result of the recent financial crisis than other firms.

For Europe and Germany it is shown that, during the financial crisis of 2008/09, banks reduced lending supply to the real sector (Bundesbank 2009; Cingano et al. 2016; Iyer et al. 2014; Meriläinen 2016). At the same time, for obvious reasons, demand for debt increased (Armstrong et al. 2013; Cowling et al. 2012) and Lee et al. (2015) as well as North et al. (2013) show that innovative firms face more severe problems in accessing external financing during the financial crisis. In addition, empirical evidence is provided that the restrictions in access to external financing during the recent financial crisis affected investment expenditures negatively (e.g. Almeida et al. 2012; Campello et al. 2011; Cingano et al. 2016; Vermoesen et al. 2013). In contrast, the effects on innovation activity due to reduced bank lending during the recent financial crisis remain unclear.

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

As already noted in the introduction, one major reason for the refinancing problems of banks were tensions on the interbank market (see below in more detail). Consequently, our identification strategy relies on the observation that the banks use the interbank market non-uniformly to refinance their loan supply to the real sector. Based on this fact, we can detangle demand- and supply-side factors that likewise play a role during major economic downturns. Applying this approach, we are able to provide causal evidence on the impact of changes in bank lending on the reduction of corporate innovation activities during the financial crisis due to funding shortages, the initiation of new innovation activities and the reallocation of human resources to innovation.

3. Data and empirical strategy

3.1 Data and variables

Our database consists of 1449 non-financial[4] firm information from the Mannheim Innovation Panel (MIP) which is combined with bank balance sheet information. The MIP represents the German section of the European CIS Survey. It has been conducted annually since 1993 and focusses on the innovation activities of firms. Besides general firm information, the MIP surveys 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.

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.[5]

Applying this matching procedure allows us to investigate the transmission of specific bank shocks on the corporate customers. The MIP 2010 wave included a specific section on the consequences of the financial crisis on innovation and this allows us to identify the effects of financial constraints on firms' innovative activity during the crisis. We use a unique item from

[4] Firms in our sample are operating in the manufacturing industry and knowledge-intensive services.
[5] For private banks, headquarter balance sheet information is applied.

the MIP survey in 2010 which surveys managers' evaluation of the consequences of the financial crisis 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?" and the subsequent question: "Reduction of innovation activities due to funding shortages". The response options are simply *yes* or *no*. Financing may be either internal or external. This question allows us to directly measure the impact of constraints on the financing of actual innovative activities. 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 the following two questions of the same section of the MIP which collects information on the initiation of innovation activity in 2009 due to the financial crisis. The first question is on additional product innovation: "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". Again, the response options are just *yes* or *no*. These questions give an insight into enhanced innovation activity due to the crisis and offer an opportunity for identifying the impact on upcoming innovation activity. We create two dummies, 'Initiation of product innovation' and 'Initiation of process innovation'. Unit value is assigned if the firms answered the related questions with yes and zero if not.

Besides the specific actions taken towards current innovation activities and the initiation of future innovation, we consider the issue whether firms reallocate labor to the innovation department. Within the same sub-section focusing on the change in innovation activities due to the financial crisis, the following question is included: "Use of free human resources for increased innovation activities". Reallocation of human resources increases capacities for innovation. Thus, we create the variable 'Reallocation of human resources to innovation' and assign unit value if the firm undertook this measure and zero if not.

We also have access to several firm-specific variables as of 2009. The baseline explanatory variables include standard variables such as the logarithm of age 'lnAge', size measured by the logarithm of the number of employees 'lnEmployees', and its square 'lnEmployees squared', membership to a group of firms 'Part of firm group' and location in eastern Germany 'Located in eastern Germany'.

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. This question allows for a direct assessment of the dependence on and availability of internal financing. The resulting dummies 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.

Additionally, a rating index 'Firm rating' is included to represent risks associated with the individual companies.[6] 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 and Hottenrott 2011a & 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.

Moreover, we have access to the loan growth of the firm's main bank. As we are considering changes in innovation behavior in 2009, the loan growth is measured from 2008 to 2009 such that the variable is generated as $\Delta\text{Lending}_j = \frac{\text{Lending}_{2009} - \text{Lending}_{2008}}{\text{Lending}_{2008}}$. 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 cope for the influence of the financial crisis on the relevance of interbank borrowing in relation to total assets.[7] In addition, we create a dummy variable 'Cooperative bank' which takes unit value if the firm's main bank is a cooperative bank and zero otherwise[8].

[6] We impute missing rating observations by lagged rating values. See e.g. Czarnitzki and Toole (2011) for a similar approach.
[7] In 2009, the Dresdner Bank and Commerzbank merged. Since we do not want to create a selection problem by dropping those observations, we cope with their merger by using the mean (38.175) of both banks' 2006 interbank values. The approach is appropriate since both banks are quite similar with respect to bank type, size and other balance sheet characteristics. In addition, in our sample, the interbank values for Dresdner bank (37.575) and Commerzbank (38.775) are close together.
[8] This type of bank used interbank refinancing to a very low degree. See below.

Descriptive statistics for our baseline sample are shown in Table 1. Roughly 20 percent of the firms in our sample decreased their innovation expenditures due to financing constraints during the crisis. The mean of the 'Interbank' variable implies that the average share of interbank market loans to assets is 26 percent. About 19 percent of the firms in our sample have a business relationship to a cooperative bank.

Table 1: Descriptive statistics (N=1449).

	Mean	SD	Median
Dependent variables			
Reduction in innovation activities	0.202	0.402	0.000
Initiation of product innovation	0.451	0.498	0.000
Initiation of process innovation	0.440	0.497	0.000
Reallocation of human resources to innovation	0.276	0.447	0.000
Firm controls			
Employees in thousands	0.273	1.284	0.040
Age	30.072	33.401	18.000
Located in eastern Germany	0.346	0.476	0.000
Part of firm group	0.446	0.497	0.000
No influence of profit reduction	0.222	0.416	0.000
Low influence of profit reduction	0.184	0.387	0.000
Med influence of profit reduction	0.253	0.435	0.000
High influence of profit reduction	0.341	0.474	0.000
Firm rating	227.059	50.326	222.000
Bank balance sheet information			
Interbank*100	0.255	0.116	0.299
Cooperative bank	0.188	0.391	0.000
ΔLending	-0.044	0.177	-0.021

3.2 Empirical strategy

We are interested in measuring the impact of changes in the loan supply of banks on three different outcomes: Firstly, the probability of reducing innovation activity, secondly, the probability of initiating additional product or process innovations and, thirdly the reallocation of human resources to innovation. Thus, the relationship between bank loan growth and innovation activity might be described by the following Probit relationship:

$$\Pr(I_i) = \Phi(\beta_0 + \beta_1 \Delta\text{Lending}_{ij} + \beta_k X_{k,i} + \phi_i + \varepsilon_i) \quad (1)$$

Where $\Pr(I_i)$ represents the different probabilities of the mentioned outcomes: the probability of reducing innovation expenditures due to funding shortages during the financial crisis, initiating

new product or process innovations or reallocating of human resources to innovation. $\Delta\text{Lending}_{ij}$ comprises the loan growth of a firm's main bank in 2009. X_k consists of several firm-specific variables as described above and ϕ_i is a set of industry dummies. The error term is described by ε_i.

The presented specification (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. 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. In order to identify the causal effect of debt on innovation, we need to instrument our variable $\Delta\text{Lending}$.

Therefore, we apply the two-stage conditional maximum likelihood estimator (2SCML) as proposed by Rivers and Vuong (1988).[9] The estimation strategy is related to the usual two-step approach. First, we run a first-stage OLS regression of $\Delta\text{Lending}$ on all variables from equation (1) and a vector Z_n of variables which are correlated with our endogenous variable $\Delta\text{Lending}$, but not with the decision to reduce innovation activity or to initiate new innovation projects:

$$\Delta\text{Lending} = \gamma_0 + \gamma_n Z_n + \gamma_k X_k + \phi_i + \mu_i \qquad (2)$$

In the second stage, we plug the residuals of the first-stage regression (2) into the Probit equation (1). Standard errors are obtained by 200 bootstrap replications. This approach has two advantages: First, we are able to assess the endogeneity of the $\Delta\text{Lending}$ variable by inspecting the significance of the coefficient of the residuals as suggested by Wooldridge (2002, p. 474). Second, 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).

The suitability of our instruments 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 instruments. 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.

[9] See Terza et al. (2008), Seid and Gurmu (2015) as well as Alesandrini et al. (2010) for recent applications.

In addition, we report the usual two-stage least squares results (2SLS) from the Stata module ivreg2 by Baum et al. (2010).[10] This module allows us to present additional diagnostic tests on the validity of our instruments. For a verification of the exogeneity of our instruments, we present the Hansen J-statistic for a test of overidentifying restrictions. Thus, we report a test statistic for the null that instruments and error term of the second stage are uncorrelated. In addition, we report the Kleibergen-Paap rk LM statistics[11] testing for underidentification.

3.3 Instruments for bank loan supply

The financial crisis affected supply and demand, and we use an instrumental variable which shifts the supply side of credit growth to detangle the effects of both sides of the debt market. The first instrumental variable is the interbank relation of the individual banks. Secondly, we make use of the institutional characteristics of banks and apply an indicator that exploits their institutional affiliation.

The German banking system is based on three pillars, which can be separated into private, savings and cooperative banks. These types differ with respect to market share, international activities, loan funding and more generally the business strategy. Among the three types, the cooperative and savings banks mainly operate regionally and engage in customer deposit taking to obtain liquidity for loan supply. These customer deposits remain relatively stable even in financial downturns like the recent financial crisis (e.g. Cornett et al. 2011). Savings and cooperative banks access international markets for liquidity predominantly via their head institutions. These are regionally distributed Landesbanken for the savings bank pillar and cooperative central banks for the cooperative banks pillar. In contrast to cooperative and savings banks, the private banks obtain liquidity to a higher degree from other sources like the interbank market. Problems with respect to asymmetric information concerning borrower quality prevail in this market (e.g. Rochet and Tirole 1996; Freixas and Holthausen 2005). Consequently,

[10] 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.

[11] The reported statistic is for the null that the excluded instruments are not correlated with the endogenous variable.

disruptions on the interbank market affect liquidity distribution in the financial system and costs of funds negatively.[12]

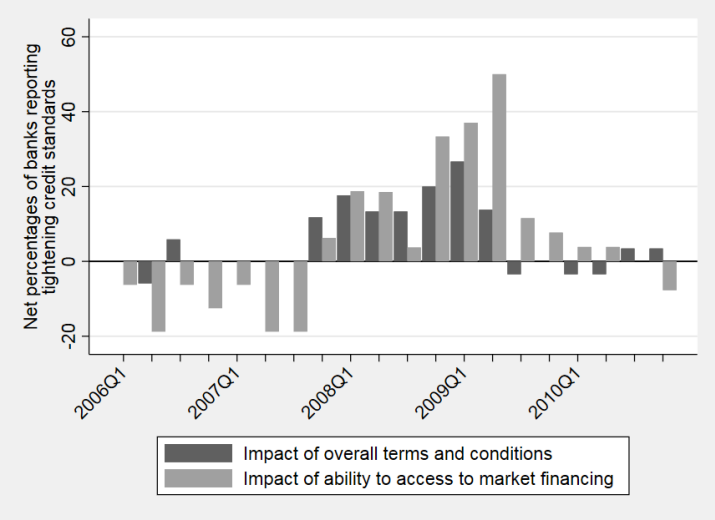
The financial crisis of 2008/2009 marks a period of stress on financial markets which reached its peak with the breakdown of Lehman Brothers in late 2008 (Acharya and Merrouche 2012). After this event, the turmoil on the interbank market led to loss of trust between banks, resulting in sharply increased spreads, liquidity holding and – related with this – a much lower supply of financial resources (Acharya and Skeie 2011; Acharya and Merrouche 2012; Ashcraft et al. 2011 and in particular for Germany Craig and von Peter 2014 and IMF 2016).

Using the results of the German part of the Bank Lending Survey (BLS), it is possible to depict the impact of the ability to raise money on financial markets on the credit supply standards of banks during the financial crisis. As shown in Figure 1, banks indeed report a stricter tightening of credit standards for loans to non-financial firms in the years 2008 and 2009. This tightening occurred on a general basis and was a result of their ability to access market financing.[13] The Bundesbank (2009) and IMF (2016) also 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 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).

[12] Even if the banks do not participate in the interbank market on their own but via a central institution, the ability of the central institution to transmit funds to smaller banks is hampered. Liberati et al. (2015) shows that key players in the European interbank market exert their market power in times of disruption on the interbank market. They could reverse their lending behavior and hoard cash or demand higher interest rates.

[13] Reported are net percentage changes as the difference between the shares of banks reporting tightening credit standards and banks reporting eased credit standards due to the ability to access market financing in the previous three months. A positive value indicates tightening credit standards, while a negative value indicates eased credit standards.

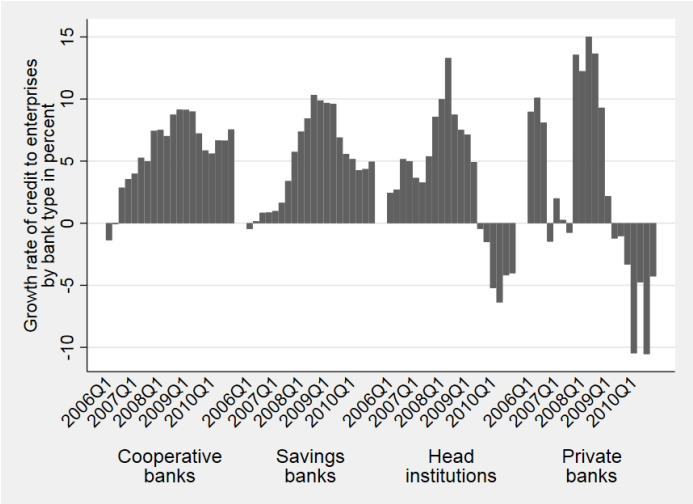
Figure 1: Change in credit standards due to the ability to access market financing. Source: BLS (own calculations)



As already noted, the refinancing of banks by the interbank market largely depends on business strategy and this in turn is related to the bank type. Besides funding strategies, bank types differ according to their ownership structure. In times of monetary policy contractions, bank ownership has an effect on the lending adjustments of banks (e.g. De Santis and Surico 2013; Ferri et al. 2014). Thus, the bank type delivers valuable information on the bank's business model and therefore its ability to lend during the crisis. Private banks are profit-oriented and distribute profits to their shareholders. Cooperative banks are owned by their typically local members, who are also depositors (Lang and Welzel 1996). Their owners do not benefit from retained earnings and there is no room for control by large owners, as the 'one member, one vote' rule applies (Ferri et al. 2014; Lang and Welzel 1996). Moreover, this bank type is less incentivized to take risks in terms of lending to customers with a high probability of default (Forteyne 2007). Savings banks belong to the public bank sector, stick to the regional principle such that they provide financial services for customers in their region and are allowed to deviate from profit maximization (Behr et al. 2013; Puri et al. 2011). They are engaged in less risky operations than the Landesbanken, their head institutions (Puri et al. 2011). Consequently, cooperative and savings banks can deviate from strict profit maximizing, engage in less risky activities and have a higher focus on regional credit supply than private banks.

Taking bank business models into consideration, empirical studies (e.g. Meriläinen 2016) find that cooperative and publicly owned savings banks in Europe were not hit by the crisis as severely as other bank types (including their lending behavior). However, some savings banks in Germany suffered as a result of the crisis as they had the obligation to support their head institutions in times of financial distress (Puri et al. 2011). Differences among bank types are reflected in aggregate figures on the development of the volume of loans. Figure 2 depicts the quarterly growth rate of loans to German enterprises compared to the same quarter in the previous year. The growth of loans to German enterprises started to decrease in 2008 for private banks and the head institutions of the cooperative bank and savings bank sector. The growth rate declined slightly for cooperative and savings banks but remained on a positive level.

Figure 2: Mean growth rate of loans to German enterprises and self-employed persons
Source: Bundesbank (own calculations)



The data demonstrates the differences between the bank types and shows in accordance with the literature (Cingano et al. 2016, Iyer et al. 2014) that the instrumental variable 'Interbank' is highly (negatively) correlated with our endogenous variable ΔLending.[14] Consequently, we expect that higher interbank market borrowing activities prior to the crisis will exert a negative effect on bank lending during the crisis. Moreover, the figures indicate that bank lending differs

[14] The first-stage regression result in Table 2 provides a further insight concerning the correlation between instruments and ΔLending.

by bank type during the financial crisis. Accordingly, we expect that cooperative banks will have on average a higher lending growth during the financial crisis than all other types.

It has to be noted that both the interbank ratio and the bank type indicator of banks are assumed not to be directly related to the innovativeness of firms. First, 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 and Kraft (2017), the interbank ratio did not exert any significant influence on firm innovation expenditures in the time prior to 2008. The same holds for cooperative banks and discontinued innovation projects as shown by Kipar (2011).

4. Results

4.1 Reduction of innovation activities during the crisis

We first shed light on the first-stage estimation results in Table 2, column (1). As explained above, in the context of the crisis period the negative sign of the (highly significant) Interbank coefficient in the first column (1) is to be expected. Additionally, the coefficient size is comparable to the magnitude of the interbank market variables in the studies by Cingano et al. (2016) and Iyer et al. (2014). The cooperative bank dummy is positive and also highly significant at the one percent level.[15] This indicates that cooperative banks indeed have a higher credit supply in 2009 compared to 2008. This finding coincides with the arguments made above. Moreover, the F-test reported at the bottom of the table supports the validity of our instruments. The value of 88.902 far exceeds the critical value of ten indicating that our instruments are valid with respect to the influence on the endogenous variable.

In a next step, we analyze the impact of bank loan growth on the reduction of innovation activities during the crisis due to funding shortages. Results are given in columns (2) and (3) in Table 2. In column (2), we report the results of the usual 2SLS estimation. Firstly, the overidentification test at the bottom of the table reveals that the null of no correlation between instruments and error term of the second stage cannot be rejected. Moreover, the underidentification test reported by the p-value of the Kleibergen-Paap rk LM statistic is rejected. Thus, our instruments are truly valid in the context of being correlated with the endogenous

[15] It could also be shown that our instruments independently exert significant variation in the ΔLending variable.

variable but not with the variable indicating reduction of innovation activities. 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 average marginal effect reveals that a one-percentage-point increase in loan growth leads to a reduction of the probability of reducing innovation activities due to funding shortages during the crisis by 0.433 percentage point.

The 2SCLM results of interest are shown in column (3). First, the coefficient of the predicted residuals from the first stage is significant at the one percent level. This indicates that there is indeed an endogeneity problem with respect to the loan growth variable. Furthermore, the coefficient of the loan growth variable is again negative and highly significant. According to the computed marginal effect an increase of loan growth by one percent would lead to a 0.445 percentage lower probability of reducing innovation activity during the crisis due to funding shortages. This result is in line with the findings of Cingano et al. (2016), who show that firms with a bank with higher interbank usage face lower loan growth and therefore lower investment expenditures.

Concerning the control variables, we find a U-shaped effect for size. This indicates that the probability of reducing innovation activity due to the crisis decreases up to a size of 212 employees (column (3)), while it increases thereafter. We do not find significant effects for age, geographical location and being part of a firm group. Our results indicate that a greater importance of profit reduction leads to a higher probability of innovation expenditure reduction. Additionally, the rating coefficient is positive and highly significant. This indicates that firms with a weaker rating and therefore lower financial strength, as well as worse access to external finance, are more likely to reduce their innovation activity during the crisis as a result of funding shortages.

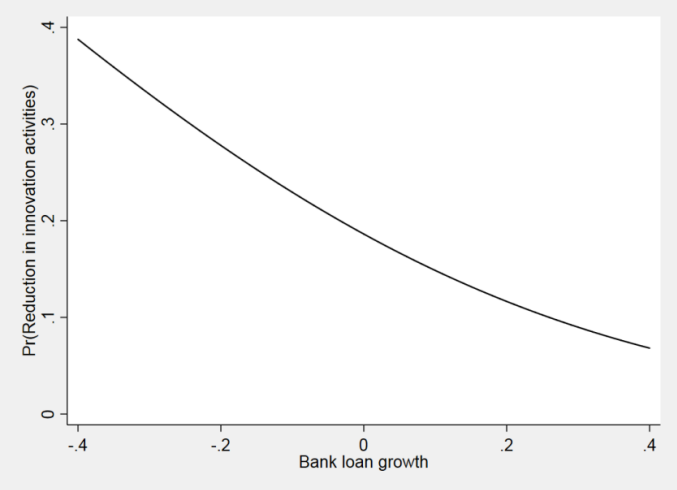
Table 2: Reduction in innovation activities due to funding shortages during the crisis estimation results

Dependent variable	(1)	(2)	(3)
	First stage	Reduction of innovation activities	
	OLS	2SLS	2SCML
ΔLending		-0.440***	-1.797***
		(0.132)	(0.590)
ΔLending [AME]			[-0.450***]
First-stage residual			2.229***
			(0.612)
lnEmployees	0.009	-0.059**	-0.225**
	(0.011)	(0.027)	(0.109)
lnEmployees squared	-0.002	0.006**	0.021*
	(0.001)	(0.003)	(0.011)
lnAge	0.009	-0.016	-0.061
	(0.006)	(0.014)	(0.053)
Located in eastern Germany	-0.032***	-0.040*	-0.167*
	(0.009)	(0.024)	(0.101)
Part of firm group	-0.012	-0.005	-0.011
	(0.008)	(0.024)	(0.102)
Low influence of profit reduction	-0.004	0.018	0.152
	(0.016)	(0.023)	(0.163)
Med influence of profit reduction	-0.012	0.124***	0.658***
	(0.012)	(0.026)	(0.144)
High influence of profit reduction	-0.030***	0.268***	1.111***
	(0.011)	(0.027)	(0.141)
Firm rating	0.000	0.001***	0.003***
	(0.000)	(0.000)	(0.001)
Interbank	-0.503***		
	(0.049)		
Cooperative bank	0.073***		
	(0.017)		
Constant	0.020	0.082	-1.411***
	(0.055)	(0.119)	(0.459)
Industry dummies	Yes	Yes	Yes
F-test of excluded instruments	88.111		
Overidentification		0.208	
Underidentification		0.000	
Log Likelihood	654.837	-672.677	-633.448
Obs.	1449	1449	1449

Standard errors in parentheses. Robust standard errors computed for 2SLS. Standard errors obtained by 200 bootstrap replications for 2SCML. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

Figure 3 illustrates the impact of increased loan growth ΔLending on the probability of reducing innovation activities. The probability of reducing the innovation activities due to funding shortages decreases from 20% to 15% if the firm is related to a bank that has a one standard deviation higher loan growth rate than the median bank.

Figure 3: Predictive margins for reduction in innovation activities due to funding shortages at levels of bank loan growth



4.2 Initiation of new innovation activities in the crisis

In this section we report our findings concerning the probability of initiating new innovation projects subject to the loan growth of the firm's main bank. The results are shown in Table 3. The outcome of the overidentification tests in columns (2) and (5) support our assumption on the exogeneity of our instruments. Again, we find a high correlation of the instruments and the endogenous variable as displayed in the underidentification test. Additionally, the inserted predicted residuals from the first stages are significant at least at the five percent level in columns (3) and (6). This supports the notion that instrumenting the loan growth variable is necessary as before.

The coefficients of interest in columns (2) and (4) are significant at least at the five percent level. The results of the average marginal effects show that an increase of loan growth by one percentage point leads to a 0.566 percentage point higher probability of initiating a product innovation (column 2). With respect to the process innovation, a one unit increase in the loan

growth rate leads to a 0.386 percentage point higher probability of initiating a process innovation (column 3).

For the remaining control variables in column (2), we observe a similar effect for size as in Table 2. Thus, the probability of initiating a product innovation increases with the number of employees, but turns out to become negative when the firm reaches a size of 139 employees. Next, the probability of initiating a product innovation decreases with age. Again we find no significant effect for location of the firm and being part of a firm group. Similarly to the results in Table 3, we find a positive influence of firm rating on the probability of initiating a new product innovation. The negative sign therefore indicates that a weaker rating leads to a lower probability of initiating a new product innovation. The results are quite similar for the initiation of process innovation (columns (3) and (4)). One difference is that the squared size term in columns (3) and (4) turns out to be insignificant.

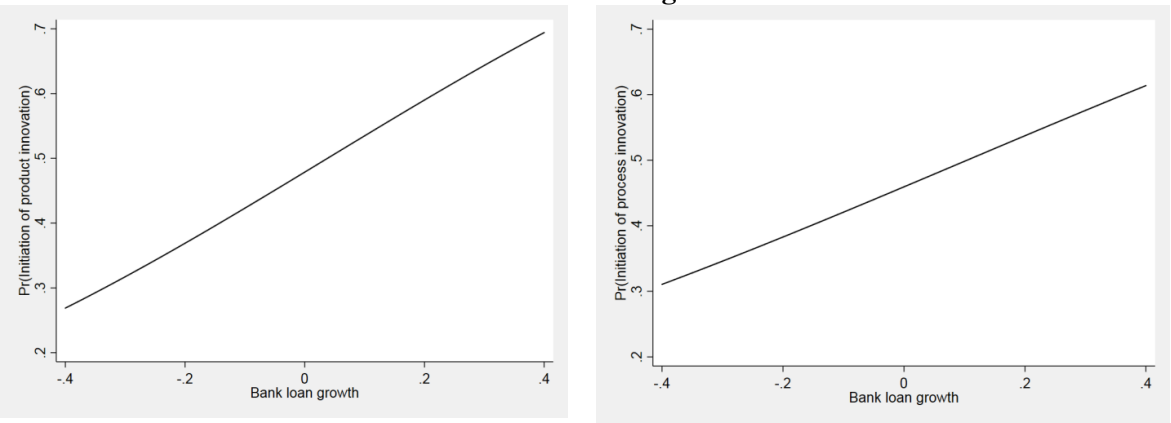
Table 3: Initiation of additional innovation activities estimation results

Dependent variable	(1)	(2)	(3)	(4)
	Initiation of product innovation		Initiation of process innovation	
	2SLS	2SCML	2SLS	2SCML
ΔLending	0.564***	1.470***	0.390**	1.018**
	(0.175)	(0.509)	(0.174)	(0.467)
ΔLending [AME]		[0.582***]		[0.401**]
First-stage residual		-1.548***		-1.278**
		(0.563)		(0.520)
lnEmployees	0.089***	0.237**	0.071**	0.188*
	(0.033)	(0.097)	(0.034)	(0.105)
lnEmployees squared	-0.009***	-0.024**	-0.005	-0.013
	(0.003)	(0.010)	(0.004)	(0.011)
lnAge	-0.047***	-0.123***	-0.041**	-0.108**
	(0.017)	(0.045)	(0.017)	(0.049)
Located in eastern Germany	0.024	0.062	-0.014	-0.037
	(0.030)	(0.080)	(0.030)	(0.080)
Part of firm group	-0.006	-0.014	0.036	0.095
	(0.030)	(0.082)	(0.030)	(0.082)
Low influence of profit reduction	0.037	0.101	0.004	0.011
	(0.042)	(0.105)	(0.042)	(0.109)
Med influence of profit reduction	0.104***	0.272***	0.089**	0.233**
	(0.038)	(0.100)	(0.038)	(0.100)
High influence of profit reduction	0.079**	0.208*	0.072*	0.187*
	(0.037)	(0.107)	(0.037)	(0.098)
Firm rating	-0.001**	-0.002**	-0.000	-0.001
	(0.000)	(0.001)	(0.000)	(0.001)
Constant	0.498***	0.004	0.493***	-0.016
	(0.140)	(0.402)	(0.142)	(0.423)
Industry dummies	Yes	Yes	Yes	Yes
Overidentification	0.737		0.346	
Underidentification	0.000		0.000	
Log Likelihood	-1038.590	-966.427	-1032.600	-968.649
Obs.	1449	1449	1449	1449

Standard errors in parentheses. Robust standard errors computed for 2SLS. Standard errors obtained by 200 bootstrap replications for 2SCML. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

Predictive margins for both outcomes are shown in Figure 4, panels (a) and (b). Both graphs are slightly curved. Moreover, the graphical depiction reveals that an increase in bank loan growth leads to a greater probability of introducing a product innovation than of initiating a process innovation.

Figure 4: Predictive margins for the introduction of product and process innovation at levels of bank loan growth



(a) Product innovation (b) Process innovation

The effects shown in Tables 2 and 3 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 pro-cyclical behavior.

4.3 Effect on the reallocation of human resources to innovation

In this section, we analyze the behavior of firms with respect to the alternative allocation of labor in dependence on their main bank's loan growth. As argued above, firms likewise shift financial and other resources to more essential projects if access to financing becomes worse. Vice versa it is probable that firms shift resources to the innovation department when facing a relatively good financing situation in an economic downturn. Thus, we expect that firms which are related to a bank with a higher loan growth will more likely increase human resources in the innovation department.

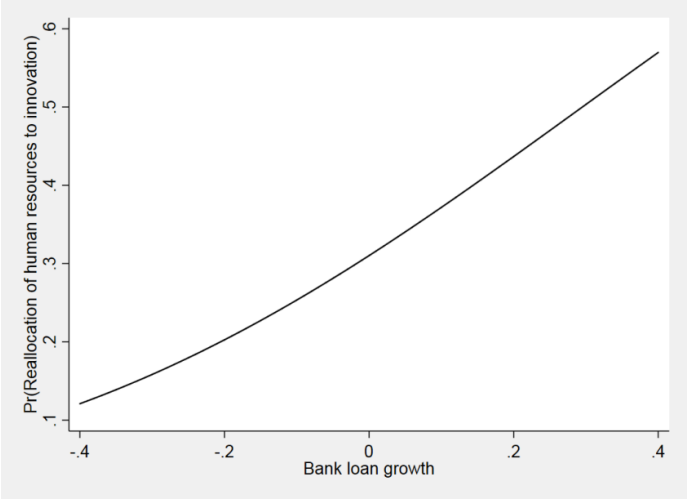
Table 4 shows the estimation results for the dependent variable indicating whether firms shift free human resources to innovation projects as a reaction to the financial crisis. Our hypothesis gets empirical support as a one percent higher bank loan growth induces a 0.585 percentage point increase in the likelihood to reallocate human resources to innovation in the crisis. Predictive margins in figure 5 show that probability of shifting free human resources to the innovation department is increasing roughly linear with increasing bank loan growth.

Table 4: Estimation results for the question whether firms shift human resources to the innovation department

Dependent variable	(1) Reallocation of human resources to innovation	(2) Reallocation of human resources to innovation
	2SLS	2SCML
ΔLending	0.600***	1.779***
	(0.168)	(0.542)
ΔLending [AME]		[0.585***]
First-stage residual		-2.349***
		(0.606)
lnEmployees	0.068**	0.231**
	(0.027)	(0.111)
lnEmployees squared	-0.006**	-0.021*
	(0.003)	(0.012)
lnAge	-0.045***	-0.139***
	(0.016)	(0.050)
Located in eastern Germany	0.006	0.015
	(0.028)	(0.084)
Part of firm group	-0.017	-0.049
	(0.027)	(0.082)
Low influence of profit reduction	0.072**	0.241*
	(0.036)	(0.124)
Med influence of profit reduction	0.095***	0.312***
	(0.034)	(0.116)
High influence of profit reduction	0.155***	0.490***
	(0.033)	(0.116)
Firm rating	-0.000	-0.001
	(0.000)	(0.001)
Constant	0.238*	-0.821*
	(0.123)	(0.457)
Industry dummies	Yes	Yes
Overidentification	0.936	
Underidentification	0.000	
Log Likelihood	-905.969	-820.613
Obs.	1449	1449

Standard errors in parentheses. Robust standard errors computed for 2SLS. Standard errors obtained by 200 bootstrap replications for 2SCML. Significance: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.

Figure 5: Predictive margins for the reallocation of human resources to innovation at levels of bank loan growth



5. Conclusion

We provide evidence for the existence of a relationship between the liquidity 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 use instrumental variable estimation to explain the innovation activities in the crisis by the loan growth of a firm's main bank. We exploit the exogenous variation in bank loan supply by applying two different instruments for bank loan growth: the type of bank institution as well as the interbank market borrowing ratio. 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.

Our results have two implications for the existing literature on the relationship between banks and firm innovations. First, we are able to show the relation between external bank financing and corporate innovation on the firm level. Former analyses mostly concentrate on the county or country level (e.g. Allessandrini et al. 2010; Amore et al. 2013). Second, we are able to support the finding that credit constraints lead to pro-cyclical innovation behavior in economic downturns

(e.g Aghion et al. 2012). In addition, our results also support the result that firms without credit constraints invest in innovation projects in a pro-cyclical manner.

The result of the analysis has several policy implications. First, in global economic downturns innovative firms suffer the most, due to their business model. Thus, these firms are more likely to need support in times of hampered access to external financing. We propose subsidies as analyzed by Brautzsch et al. (2016) and Hud and 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 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.

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