Discussion Paper No. 17-064

External Financing Constraints and Firm's Innovative Activities During the Financial Crisis

Marek Giebel and Kornelius Kraft

ZEW
Zentrum für Europäische Wirtschaftsforschung GmbH
Centre for European Economic Research

Discussion Paper No. 17-064

External Financing Constraints and Firm's Innovative Activities During the Financial Crisis

Marek Giebel and Kornelius Kraft

Download this ZEW Discussion Paper from our ftp server:

http://ftp.zew.de/pub/zew-docs/dp/dp17064.pdf

Die Discussion Papers dienen einer möglichst schnellen Verbreitung von neueren Forschungsarbeiten des ZEW. Die Beiträge liegen in alleiniger Verantwortung der Autoren und stellen nicht notwendigerweise die Meinung des ZEW dar.

Discussion Papers are intended to make results of ZEW research promptly available to other economists in order to encourage discussion and suggestions for revisions. The authors are solely responsible for the contents which do not necessarily represent the opinion of the ZEW.

External financing constraints and firm's innovative activities during the financial crisis

by

Marek Giebel[a] and Kornelius Kraft[b]

October 2017

Abstract

We investigate the effect of individual banks' liquidity shocks during the recent financial crisis of 2008/2009 on the innovation activities of their business customers. Individual banks' liquidity shocks are identified by the degree of interbank market usage. We use a difference-in-differences approach to identify the effect of interbank reliance during the crisis on total innovation expenditures in comparison to the periods before. Our results imply that those firms which have a business relation to a bank with higher interbank market reliance reduce their innovation activities during the financial crisis to a higher degree than other firms.

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

Keywords: Financial crisis, financial constraints of banks, financing of innovation, innovation activity

[a] Corresponding author at: TU Dortmund University, Faculty of Business, Economics and Social Sciences, Vogelpothsweg 87, D-44227 Dortmund, Marek.Giebel@tu-dortmund.de
[b] TU Dortmund, Faculty of Business, Economics and Social Sciences, Vogelpothsweg 87, D-44227 Dortmund, ZEW Mannheim, IZA Bonn and KU Leuven, Belgium, Kornelius.Kraft@tu-dortmund.de

1. Introduction

It is well known that innovation activity is a major determinant of technological progress and of growth of an economy (Aghion and Howitt 2009; Grossman and Helpman 1994; Solow 1957). At least since Schumpeter (1911) it is also widely recognized that technological progress and economic growth is associated with the availability of financial resources, and this is not an easy relationship if external financing is considered. Asymmetric information problems like adverse selection and moral hazard cause external financing constraints (Hall 2002). These constraints seriously hamper innovation activities and, consequently, technological progress and growth (e.g. Hall 2002).

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 and 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 2013; 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 does not exist.[1]

The purpose of the paper is to fill this gap by investigating the effects of the financial crisis on innovation activity. Our approach relies on the financial crisis as an unexpected, exogenous and drastic distortion of financial markets, which had serious consequences for the lending behavior of banks. We use the fact that the collapse of the interbank market led to lending reductions 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, we utilize as a cross-sectional dimension the interbank reliance of banks and then estimate the impact of this relative engagement on their corporate customers' innovative activities within a difference-in-differences context.

[1] To our knowledge there exists literature investigating the effect of specific firm characteristics on innovation activity in the financial crisis (e.g. Amore 2015; Archibugi et al. 2013a & 2013b; Campello et al. 2010; Filippetti and Archibugi 2011; Paunov 2012).

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 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.

Our difference-in-differences estimates imply that it is indeed more likely that innovation expenditures will be reduced during the crisis due to financing constraints if the firm's bank relies heavily on the interbank market. 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 as an activity largely unrelated to technical progress, much less connected with uncertainty than innovation and a regular firm activity. Here we find no effect of banks' reliance on the interbank market.

Our study is structured as follows. In Section 2 we discuss both the institutional and the theoretical background. Section 3 explains the relationship between the financial crisis and the real economy[2]. In the next section data, methodology and results for the test concerning financial constraints of banks and the relation to financing problems of innovative activities are presented and discussed. The fifth and last section comprises our conclusion.

2. Related Literature

2.1 External innovation financing

It is generally acknowledged that R&D investment differs from investment in normal assets (Hall 2002). This is rooted in the nature of R&D expenditures, which provide low collateral, are usually sunk and uncertain with respect to outcome and market success (Hall 2002). Among others, Himmelberg and Petersen (1994) as well as Czarnitzki and Hottenrott (2011b) show that

[2] Real economy comprises the part of the economy (e.g. firms) that has the objective of producing goods and services rather than financial services (e.g. banks).

internal means are more important for R&D investment than for ordinary investments. These and other studies (e.g. Bond et al. 2005; Brown et al. 2012; Harhoff 1998; Hottenrott and Peters 2012) demonstrate that internal financing constraints have a negative effect on R&D spending.

Originating in asymmetric information between investors and inventors, financing of R&D has aspects of Akerlof's (1970) market for lemons and is characterized by high "lemon premia" (Hall and Lerner 2010). Likewise, it is more difficult to obtain external finance for R&D investments than for other investments (Hall and Lerner 2010). Using a credit rating index as proxy for access to external finance, Czarnitzki and Hottenrott (2011a, 2011b) show that external financing matters for R&D expenditure.[3] In addition, empirical studies like Freel (2007) and Mina et al. (2013) investigate the relationship between innovativeness and access to external finance. They emphasize that accessing external financing is indeed more difficult for highly innovative firms.

As stated above, essential for our empirical study is an indicator for individual bank liquidity shocks. Therefore, our work is related to the 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; Cornaggia et al. 2015; Hsu et al. 2014). Among these, Amore et al. (2013), Chava et al. (2013) and Cornaggia et al. (2015) show that banking deregulation in the U.S. had effects on the innovative activity of firms. Considering bank development in Italy, Benfratello et al. (2008) find a strong and robust effect on process innovation but a weaker one for product innovation. Finally, Alessandrini et al. (2010) show empirically that a bank system that is functionally more distant[4] from the local economy hampers innovation. These studies support the notion that external finance is of relevance for innovation.

2.2 Innovation expenditures during economic downturns

The empirical research on the issue of how firms adjust their innovation investments in economic downturns is ambiguous. There is evidence that R&D expenditures might be counter-cyclical without credit constraints (e.g. Aghion et al. 2012). Conversely, financing constraints, as explained above, lead to a pro-cyclical behavior of innovation activities (e.g. Barlevy 2007). In

[3] Czarnitzki and Toole (2011) find no significant influence.

[4] "Functional distance is computed as the number of branches operating in a province j, each weighted by the logarithm of one plus the kilometric distance between the capital of that province and the capitals of provinces where parent banks are headquartered" Alessandrini et al. (2010, 6).

addition, several studies (e.g. Aghion et al. 2012; López-García et al. 2013; Männasoo and Meriküll 2014; Ouyang 2011) take access to external finance into account. They find that a lack of access to external finance is a major reason for a pro-cyclical behavior of R&D investments if internal resources are scarce.

Another example, highly related to our work, is Nanda and Nicholas (2014), who investigate the effect of bank distress during the great recession on innovation. They use the share of bank suspensions[5] to total banks as a measure for county-level bank distress. Applying the indicator in a difference-in-differences context, their results imply that higher distress indeed leads to lower firm-level innovation.

3. 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 of the real economy. In such periods spillovers from disturbances from 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 debts is particularly helpful for measuring the effects on innovation activity. Following the argumentation of Nanda and 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 in general a weak access to external funding 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.[6] Moreover their own financing is largely but not solely based on deposits. Deposits do usually not

[5] According to Nanda and Nicholas (2014), suspended banks are different from failed banks because they "could subsequently re- open" (Nanda and Nicholas 2014, 278).

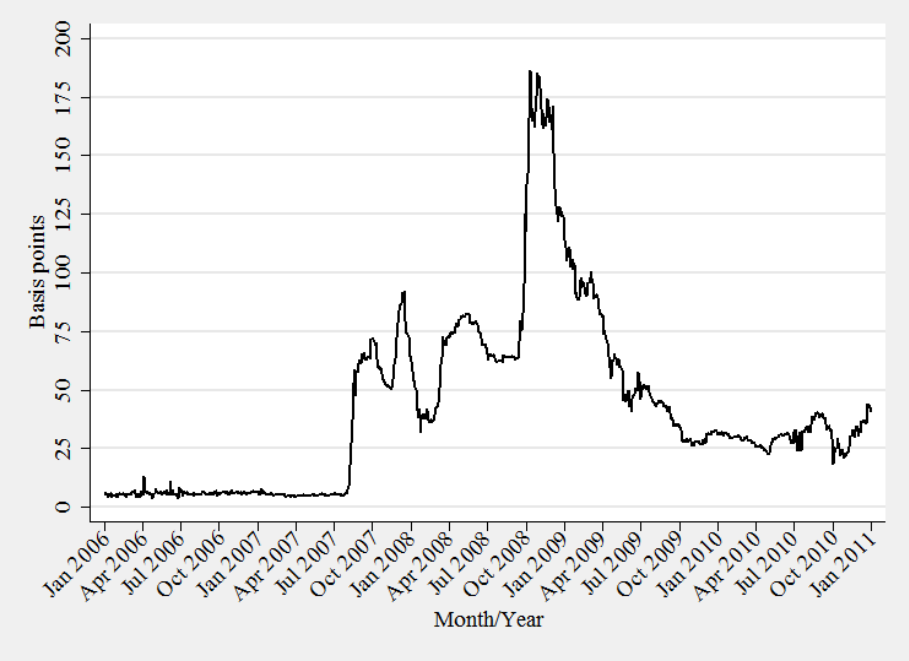
[6] Both pillars mentioned are two-tier systems themselves. Besides regional savings banks in the public banks pillar, Landesbanken serve as central institutions and are responsible for capital market transactions and refinancing at wholesale funding markets. The same holds for the cooperative bank pillar,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

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 by other resources than core deposits.

Following the description in Bräuning and Fecht (2016), there are two markets for bank liquidity in the Eurozone. First, the primary market, in which banks borrow money from the European Central Bank against collateral through open market operations (Bräuning and Fecht 2016). Second, the interbank market which plays a crucial role in the financial system by redistributing liquid assets among banks. Both banks with a surplus of liquid assets and those with a lack of liquidity use the interbank market to exchange financial resources by secured or unsecured lending. As argued in Bräuning and 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 leads to severe consequences with respect to liquidity provision and cost of funds. If there is no immediate possibility to compensate the deficit by other sources of financing, banks more likely 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 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 1: 3-Month EURIBOR-EONIA Spread. Source: German Federal Bank (own calculations)



The result of distress on the interbank market in the recent financial crisis was liquidity hoarding and a loss in trust among banks (Acharya and Skeie 2011; Ashcraft et al. 2011; Acharya and Merrouche 2012). As a consequence of hoarding and a re-shifting of liquidity, banks reduced their loan supply or applied less favorable credit conditions (Ivashina and Sharfstein 2010; Kapan and Minoiu 2013; Iyer et al. 2014).

This particular reduction in lending is also reported for Germany. Craig and 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 that are related to an affected Landesbank[7]. 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

[7] We explain the role of Landesbanken and their situation during the crisis below.

obtain external finance if financial markets are under stress (Lee et al. 2015; North et al. 2013).[8] Firms might try to find substitutes like equity financing (Kahle and Stulz 2013), but this will with all likelihood be rather difficult during such a major turmoil on the financial markets.

4. Test for changes of innovation expenditures

4.1 Data and Methodology

Our sample of 2187 non-financial firms[9] ranges from 2005 to 2010. We are able to identify the individual banks with which firms have commercial relations.[10] 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. All information on the firms is based on the Mannheim Innovation Panel (MIP), which represents the German section of the European CIS Survey. This matching affords us the opportunity to identify the possible mechanism of how shocks incurred by banks were transmitted to their clients.[11]

We use total innovation expenditures 'Total innovation expenditures' as outcome variable to investigate the effect of the degree of bank stress on corporate innovation activity. 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.

Using this information we are able to decompose total innovation expenditures into investment for innovation projects 'Investment for innovation projects' and current innovation expenditures 'Current innovation expenditures'. Investment into innovation projects covers expenditures for

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

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

[10] We do not consider firms which are switching their bank in the sample period.

[11] In the case of private banks, we used the balance sheet data for the whole bank if the firm was affiliate to a branch of the specific bank.

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.

We calculate the value of current innovation costs as the difference between total innovation expenditures and investments in innovation projects. Please note that we use repeated cross-sections, as unfortunately many firms do not participate in the survey on a regular basis. As we have repeated cross-sections for multiple consecutive years available, we apply a variant of the difference-in-differences methodology. Our treatment is a continuous variable and therefore we use a modification of the standard model. Moreover, we use several pre- and post- treatment periods and apply difference-in-differences model, suggested by Imbens and Wooldridge (2009). Following Cameron and Trivedi (2009, 531), our Tobit model for a lognormal dependent variable with a threshold γ is:

$$\ln(y_{it}^*) = \alpha_0 + \delta INTERBANK_i + \tau INTERBANK_i \times POST_t + \beta_m X_m + \beta_n X_n + \rho_i + \phi_t + \varepsilon_{it}, \quad \varepsilon \sim N(0, \sigma^2) \tag{1}$$

where y_{it}^* equals one of the above-mentioned expenditures and is the unobserved latent variable. The observed dependent variable is equal to:

$$\ln(y_{it}) = \begin{cases} \ln(y_{it}^*) & \text{if } \ln\ln(y_{it}^*) > \gamma \\ \gamma & \text{if } \ln\ln(y_{it}^*) \leq \gamma \end{cases} \tag{2}$$

The dependent variables are log-transformed following the suggestion of Cameron and Trivedi (2009, 532), as firms are possibly not innovative.[12] 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. The measure is based on data from 2006 to take account of banks' pre-crisis reliance on interbank borrowing. It is quite likely that banks with a higher ratio of INTERBANK face greater problems in the crisis. We therefore expect a positive coefficient of INTERBANK.[13]

[12] Non-innovative firms report a value of zero innovation expenditures. The transformation requires that censored values of our dependent variable are set to a value γ which is smaller or equal to the smallest uncensored value. In our case, γ is slightly lower than the smallest value.

[13] 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 (38.17492) of both banks' 2006 interbank

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 × POST takes the value of the INTERBANK measure if the year is 2008 and later, and is zero for all years before 2008. Its coefficient informs us about the impact of INTERBANK on the specific expenditures due to the crisis.

X_m represents the vector of firm-specific regressors and β_m the coefficients to be estimated. We use lagged values of employees divided by 1000 'Employees in thousands' to capture the effect of firm size. In addition, we include the square to account for a non-linear relationship. Moreover, we control for possible age effects by including the variables 'Age' and 'Age squared'. In addition, we add a dummy for location in eastern Germany 'Located in eastern Germany'. 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.

As an alternative to the availability of internal means we use the lagged value of rating 'Firm rating'. 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 negatively affect innovation expenditures. In addition the lagged growth of sales volume 'Sales growth' is included. This variable is interpreted by Behr et al. (2013) as well as Carbo-Valverde et al. (2009) as a proxy variable for Tobin's Q and therefore growth and investment opportunities.

A set of one period-lagged bank controls as used before are covered in X_n. These are bank size measured in the logarithm of bank assets and return on average assets. To control for industry-specific differences, we include a set of industry dummies ρ_i. In addition, a set of time dummies

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 (37.575087) and Commerzbank (38.774753) are close together.

ϕ_t is included. ε_i represents the random error. Descriptive statistics for our sample are given in table 1.

Table 1: Descriptive statistics (N=4399).

	Mean	SD	Median
Dependent variables			
Total innovation expenditures in million	7.138	98.048	0.391
Investments in innovation projects in million	2.118	36.872	0.078
Current innovation expenditures in million	5.020	76.106	0.196
Firm controls			
Employees in thousands	0.317	2.334	0.052
Age	33.059	39.057	18.000
Located in eastern Germany	0.349	0.477	0.000
Part of firm group	0.458	0.498	0.000
Sales growth	0.077	0.756	0.039
Firm rating	218.436	47.421	216.000
Bank balance sheet information			
INTERBANK*100	26.252	11.271	31.375
Bank assets in billion	399.445	592.566	27.267
Return on assets	0.123	0.478	0.170

4.2 Baseline results

We first consider homoscedastic regressions, and subsequently test for heteroscedasticity, as coefficient estimates may be inconsistent if the assumption of homoscedasticity is violated in Tobit models. Wald tests reject the assumption of homoscedasticity for all specifications. In order to estimate a heteroscedastic Tobit, the homoscedastic variance σ is replaced with $\sigma_i = \sigma\exp(Z_i'\alpha)$ in the likelihood function (Greene 2003). We consider groupwise multiplicative heteroscedasticity by using a set of three firm size dummies based on the number of employees as well as the above mentioned dummies for age and industries. Regression results are presented in table 2.

Variables capturing the effects of size and group association 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 (RATING) is negative and highly significant. 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.

In the context of our research question, the most important variable is the treatment variable multiplied by the crisis indicator $\text{INTERBANK} \times \text{POST}$. This variable is negative in each

regression and at least significant 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). Thus, 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 28% due to the crisis.

The results of the alternative measurement clearly show that firms related to a bank which is more engaged in interbank market borrowing reduce innovation expenditure to a larger extent.[14] Moreover, the reduction in investments in innovation projects apparently determines the reduction in total innovation expenditures.

[14] Robustness tests using the mean of the INTERBANK value of the years 2004 to 2006 for each bank leads to similar results. Results are available upon request.

Table 2: Results of the heteroscedastic Tobit model on determinants of total innovation expenditures, investments for innovation projects and current innovation costs.

Dependent variable	Log of Total innovation expenditures		Log of Investments in innovation projects		Log of Current innovation expenses	
	(1)	(2)	(3)	(4)	(5)	(6)
INTERBANK	0.033***	0.012	0.025*	0.013	0.039***	0.008
	(0.008)	(0.010)	(0.013)	(0.017)	(0.010)	(0.013)
INTERBANK × POST	-0.025***	-0.025***	-0.032**	-0.032**	-0.024**	-0.025**
	(0.009)	(0.009)	(0.015)	(0.015)	(0.012)	(0.012)
L.Employees	0.489***	0.473***	0.428***	0.420***	0.544***	0.520***
in thousands	(0.069)	(0.069)	(0.133)	(0.133)	(0.074)	(0.072)
L.Employees	-0.004***	-0.004***	-0.003***	-0.003***	-0.004***	-0.004***
in thousands squared	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Age	0.010**	0.010**	0.009	0.009	0.016***	0.016***
	(0.004)	(0.004)	(0.008)	(0.008)	(0.005)	(0.005)
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)
Located in	-0.001	-0.106	-0.404	-0.461*	0.250	0.090
eastern Germany	(0.159)	(0.162)	(0.263)	(0.270)	(0.206)	(0.209)
Part of firm group	1.253***	1.210***	1.205***	1.182***	1.593***	1.522***
	(0.162)	(0.162)	(0.264)	(0.264)	(0.204)	(0.203)
L.Sales growth	0.189***	0.188***	0.392***	0.390***	0.196***	0.192***
	(0.050)	(0.050)	(0.128)	(0.129)	(0.055)	(0.056)
L.Firm rating	-0.010***	-0.010***	-0.011***	-0.011***	-0.013***	-0.013***
	(0.002)	(0.002)	(0.003)	(0.003)	(0.002)	(0.002)
L.Log of bank assets		0.110***		0.061		0.163***
		(0.035)		(0.058)		(0.044)
L.Return on assets		-0.005		0.025		-0.089
		(0.137)		(0.232)		(0.178)
_cons	11.225***	9.125***	10.498***	9.345***	8.576***	5.472***
	(0.944)	(1.172)	(1.524)	(1.863)	(1.469)	(1.701)
Industry dummies	Yes	Yes	Yes	Yes	Yes	Yes
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes
Log Likelihood	-10632.383	-10622.655	-11740.719	-11739.788	-11043.265	-11030.457
l. censored Obs.	669	669	1066	1066	935	935
uncensored Obs.	3730	3730	3333	3333	3464	3464
Obs.	4399	4399	4399	4399	4399	4399

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.

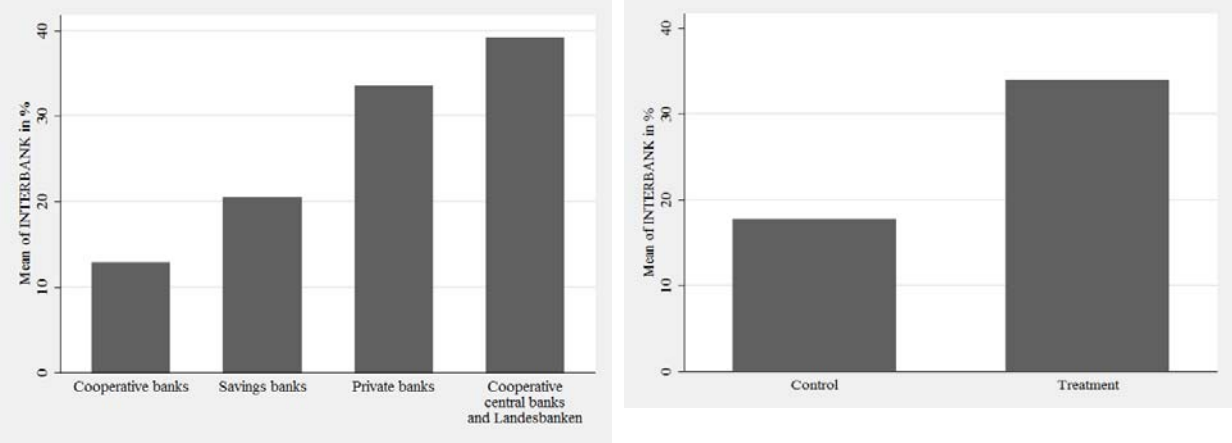
4.3 Endogeneity and Selectivity

Up to now we implicitly assume that banks and firms match randomly. However, 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.

We use inverse probability weighting to tackle selectivity on observables on the part of the firms.[15] 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. After re-weighting, the two samples of corporate customers should be equal with regard to their explanatory variables.

Clearly, obtaining the propensity score is based on a dichotomy, but our main variable of interest INTERBANK is continuous. Our approach for solving this problem is to use the German structure of the "three-pillar banking system". Thus, in principle, three kinds of banks can be distinguished: private, cooperative and publicly owned savings banks. Figure 2 shows the different INTERBANK ratios for banks sorted by group association. Private banks, Landesbanken and cooperative central banks are much more engaged in interbank borrowing. Many of them realized severe losses, to such an extent that public support was necessary in some cases to secure their survival. Thus, cooperative and savings banks were much less affected by the financial crisis than the private banks.[16] Therefore we define our treatment group by the sample of private banks, Landesbanken and cooperative central banks, while the other observations (cooperative banks and savings banks) serve as controls.

Figure 2: Mean INTERBANK values by bank type and treatment dummy.



[15] Imbens and Wooldridge (2009) propose a similar method to combine regression and propensity score weighting.
[16] See Meriläinen (2016) for an investigation of bank type-specific lending reactions due to the financial crisis. Their findings show for a European sample of banks, including Germany, that savings and cooperative banks suffered less than private banks.

Based on this categorization we apply a Probit regression to determine the propensity score. The dependent variable is the relation to a bank of the treatment group (yes/no) in order to implement a match between treated firms and control observations. To take firm size into account we use three dummy variables '1-9 employees', '10-49 employees' and '50-99 employees', which take unit values if a firm employs less than 9, between 10 and 49 or between 50 and 99 employees. The large firms form the reference group. In addition, we use similarly specified dummy variables 'Age 0-15' and 'Age 16-30' to control for firm age-specific effects. Further explanatory variables are 'Located in eastern Germany', 'Part of a firm group' and 'Firm rating'. Moreover, we use as a measure for risky activities 'mean innovation expenditures per employee'[17] which is the pre-crisis mean value of innovation expenditures per employee aggregated at the 3-digit NACE Rev. 1 industry level.

We re-estimate our results using inverse probability weights as proposed by Imbens and Wooldridge (2009). In Table A.1 of the Appendix, 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 A.2 of the Appendix. Results of re-weighted regressions are given in Table 3.[18] Again, the interaction of interest is negative and significant at least at the 10% level for total innovation expenditures, investments in innovation projects and current innovation costs. These results are similar to the earlier results presented in Table 3 and coincide with the overall results of the earlier Probit regressions.

[17] 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.
[18] 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.

Table 3: Results of the re-weighted estimation of the heteroscedastic Tobit model.

Dependent variable	Log of Total innovation expenditures		Log of Investments in innovation projects		Log of Current innovation expenses	
	(1)	(2)	(3)	(4)	(5)	(6)
INTERBANK	0.018**	0.012	0.007	0.015	0.026**	0.011
	(0.008)	(0.010)	(0.014)	(0.018)	(0.011)	(0.013)
INTERBANK × POST	-0.019**	-0.018**	-0.034**	-0.033**	-0.022*	-0.023*
	(0.009)	(0.009)	(0.017)	(0.017)	(0.013)	(0.013)
_cons	11.076***	10.433***	9.492***	10.126***	6.901***	5.561***
	(0.953)	(1.198)	(2.028)	(2.297)	(1.779)	(1.979)
Industry dummies	Yes	Yes	Yes	Yes	Yes	Yes
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes
Firm controls	Yes	Yes	Yes	Yes	Yes	Yes
Bank variables	-	Yes	-	Yes	-	Yes
Log Likelihood	-20768.113	-20765.818	-22920.768	-22919.949	-21631.268	-21625.907
l. censored Obs.	663	663	1054	1054	926	926
uncensored Obs.	3646	3646	3255	3255	3383	3383
Obs.	4309	4309	4309	4309	4309	4309

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.

4.4 Pre-crisis trend

Next we test whether there was a significant difference in investment behavior prior to the first crisis year, 2008. In Table 4, we show the results of a more flexible version of the difference-in-differences estimator, proposed by Mora and Reggio (2015):

$$\ln(y_{it}^{*}) = \alpha_0 + \delta INTERBANK_i + \sum_{t=2006}^{2010} \tau_t \times INTERBANK_i \times Year_t + \sum_{t=2006}^{2010} \phi_t Year_t + \beta_m X_{mit} + \beta_n X_{nit} + \rho_i + \varepsilon_i \quad (3)$$

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 and Reggio (2015), we evaluate the parallel trend assumption in each year and test our null on common pre-treatment trends $H_0: \tau_t = 0 \ \forall \ t \leq 2007$ simultaneously.[19] The parallel trend assumption would be met if we do not reject H_0 at the ten percent level.

Results in Table 4, panel A 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. Results in Table 4, panel B show that the same holds for the re-weighted estimations.

[19] See e.g. Hangoma et al. (2017) and Yamamura (2016) for a similar approach.

Table 4: Test for a common trend.

Panel A: Test for the non-weighted sample: H_0: common pre-treatment trends						
Dependent variable	Log of Total innovation expenditures		Log of Investments in innovation projects		Log of Current innovation expenses	
	(1)	(2)	(3)	(4)	(5)	(6)
$\chi^2_{(1)}$	0.106	0.189	0.119	0.109	0.608	0.826
p-value	0.948	0.910	0.942	0.947	0.738	0.662
Industry dummies	Yes	Yes	Yes	Yes	Yes	Yes
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes
Firm controls	Yes	Yes	Yes	Yes	Yes	Yes
Bank variables	-	Yes	-	Yes	-	Yes
Log Likelihood	-10632.159	-10622.356	-11740.488	-11739.494	-11042.863	-11029.981
l. censored Obs.	669	669	1066	1066	935	935
uncensored Obs.	3730	3730	3333	3333	3464	3464
Obs.	4399	4399	4399	4399	4399	4399
Panel B: Test for the weighted sample: H_0: common pre-treatment trends						
Dependent variable	Log of Total innovation expenditures		Log of Investments in innovation projects		Log of Current innovation expenses	
	(1)	(2)	(3)	(4)	(5)	(6)
$\chi^2_{(1)}$	0.299	0.364	0.018	0.009	0.700	0.729
p-value	0.861	0.834	0.991	0.995	0.705	0.695
Industry dummies	Yes	Yes	Yes	Yes	Yes	Yes
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes
Firm controls	Yes	Yes	Yes	Yes	Yes	Yes
Bank variables	-	Yes	-	Yes	-	Yes
Log Likelihood	-20767.071	-20764.655	-22920.332	-22919.474	-21629.009	-21623.223
l. censored Obs.	663	663	1054	1054	926	926
uncensored Obs.	3646	3646	3255	3255	3383	3383
Obs.	4309	4309	4309	4309	4309	4309

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.

4.5 Test for the effect 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[20] separately. We find a reduction of R&D expenditures, but a weaker and insignificant effect on marketing expenses. Similarly, R&D marketing activities do not offer collateral, but apparently these expenditures are regarded as being indispensable during a crisis and are not particularly risky, while R&D is definitely risky and can be delayed. The results are presented in Table 5.

[20] Data for marketing expenditures is available since 2006.

Table 5: Test for R&D expenditures and marketing expenses.

Dependent variable	Log of R&D Expenditures		Log of Marketing Expenditures	
	(1)	(2)	(3)	(4)
INTERBANK	0.046***	0.011	0.021***	0.008
	(0.015)	(0.018)	(0.008)	(0.009)
INTERBANK × POST	-0.033**	-0.033**	-0.012	-0.010
	(0.016)	(0.016)	(0.008)	(0.008)
_cons	12.942***	9.372***	11.983***	10.596***
	(0.964)	(1.530)	(0.463)	(0.693)
Industry dummies	Yes	Yes	Yes	Yes
Time dummies	Yes	Yes	Yes	Yes
Firm controls	Yes	Yes	Yes	Yes
Bank variables	-	Yes	-	Yes
Log Likelihood	-10313.978	-10305.431	-6397.812	-6391.429
l. censored Obs.	996	996	219	219
uncensored Obs.	2979	2979	2717	2717
Obs.	3975	3975	2936	2936

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. 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 with respect to information on innovation activity. We are able to identify the main bank of each firm as well as the whole bank portfolio of up to six banks. We 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 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.

Our results indicate that the firms are indeed more likely to reduce innovation activities due to the tensions on financial markets if they are related to a bank that was more strongly affected by the interbank market distortions than other banks. 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 no significant impact on this kind of expenditure, which is unrelated to technological progress.

The financial crisis offers an interesting opportunity to investigate the effect of a drastic shock to the banks, which 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.

Our results have implications for the policy debate on bank business activities, subsidization and regulation in general. Bank strategies affect the funding of loans. Recent regulatory developments of the Basle II and III accords aim at stabilizing banks by for example holding a certain amount of core capital. In addition, the German bank system kept the three-pillar structure and therefore a quite heterogeneous funding structure by core deposits and wholesale funding. Our results imply that it is necessary to implement policies for banks that guarantee a stable refinancing structure in a stress situation to secure the unconstrained credit supply to their corporate (and also private) customers.

In addition, other studies like Brautzsch et al. (2015) and Hud and Hussinger (2015) underlined the importance of public subsidies for innovative firms in an economic downturn. Consequently, if other sources of financing are scarce, policy makers should aim at programs to promote innovation activity during economic downturns.

Acknowledgements

We thank the Deutsche Forschungsgemeinschaft for funding this research by the research grant KR 929/7-1.

Appendix A: Tables

Table A.1: Matching results to obtain the propensity score for the construction of the inverse probability weights.

Year	2005	2006	2007	2008	2009	2010
Dependent variable	Treated bank	Treated bank	Treated bank	Treated bank	Treated bank	Treated bank
L.1-9 employees	-0.658***	-0.456***	-0.530**	-0.670***	-0.813***	-0.526***
	(0.246)	(0.173)	(0.216)	(0.202)	(0.252)	(0.182)
L.10-49 employees	-0.739***	-0.435***	-0.726***	-0.556***	-0.661***	-0.636***
	(0.176)	(0.130)	(0.157)	(0.139)	(0.180)	(0.128)
L.50-99 employees	-0.538***	-0.234*	-0.420**	-0.374**	-0.484**	-0.047
	(0.180)	(0.137)	(0.163)	(0.149)	(0.190)	(0.136)
Age 0-15	0.093	-0.038	-0.110	0.100	0.060	0.107
	(0.183)	(0.129)	(0.158)	(0.142)	(0.186)	(0.134)
Age 16-30	-0.267	-0.091	-0.151	0.019	0.024	-0.027
	(0.189)	(0.126)	(0.153)	(0.131)	(0.166)	(0.119)
Located in eastern	0.386**	0.674***	0.725***	0.718***	0.686***	0.654***
Germany	(0.156)	(0.106)	(0.128)	(0.112)	(0.140)	(0.103)
Part of firm group	0.301**	0.511***	0.383***	0.381***	0.525***	0.430***
	(0.132)	(0.101)	(0.120)	(0.106)	(0.132)	(0.098)
L.Sales growth	0.034	0.090	-0.081	-0.285	-0.062	-0.012
	(0.099)	(0.083)	(0.264)	(0.226)	(0.061)	(0.165)
L.Mean innovation	8.227**	5.772**	7.455**	6.626**	3.139	5.022*
expenditures per employee	(3.523)	(2.495)	(3.292)	(2.835)	(3.535)	(2.705)
L. Firm rating	-0.003*	-0.003***	-0.001	-0.005***	-0.002	-0.002**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
_cons	0.627	0.389	-0.124	0.915***	0.248	0.403
	(0.382)	(0.301)	(0.353)	(0.338)	(0.381)	(0.308)
Industry dummies	Yes	Yes	Yes	Yes	Yes	Yes
Ps. R-Square	0.130	0.114	0.128	0.144	0.140	0.117
Log likelihood	-321.204	-552.097	-386.942	-483.553	-314.804	-574.209
Obs.	538	900	640	815	528	939

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

Table A.2: Mean comparison after matching for the years 2005 to 2010. Means calculated using inverse probability weights.

		Mean		Test on mean differences
Year	Variable	Control	Treated	p-value
2005	L.1-9 employees	0.088	0.084	0.863
	L.10-49 employees	0.348	0.356	0.871
	L.50-99 employees	0.176	0.172	0.924
	Age 0-15	0.537	0.537	0.988
	Age 16-30	0.155	0.153	0.947
	Located in eastern Germany	0.414	0.403	0.824
	Part of firm group	0.530	0.521	0.864
	L.Sales growth	0.098	0.086	0.738
	L.Mean innovation expenditures per employee	0.020	0.020	0.816
	L.Firm rating	215.336	215.110	0.962
2006	L.1-9 employees	0.128	0.128	0.996
	L.10-49 employees	0.340	0.345	0.890
	L.50-99 employees	0.167	0.168	0.970
	Age 0-15	0.438	0.428	0.786
	Age 16-30	0.284	0.291	0.825
	Located in eastern Germany	0.361	0.351	0.785
	Part of firm group	0.484	0.476	0.837
	L.Sales growth	0.110	0.121	0.738
	L.Mean innovation expenditures per employee	0.022	0.022	0.967
	L.Firm rating	217.312	217.052	0.936
2007	L.1-9 employees	0.099	0.103	0.862
	L.10-49 employees	0.364	0.370	0.901
	L.50-99 employees	0.172	0.175	0.928
	Age 0-15	0.352	0.356	0.940
	Age 16-30	0.336	0.339	0.928
	Located in eastern Germany	0.360	0.374	0.739
	Part of firm group	0.474	0.461	0.772
	L.Sales growth	0.116	0.123	0.750
	L.Mean innovation expenditures per employee	0.022	0.021	0.771
	L.Firm rating	216.167	217.165	0.799

Table A.2 continued

		Mean		Test on mean differences
Year	Variable	Control	Treated	p-value
2008	L.1-9 employees	0.096	0.096	0.998
	L.10-49 employees	0.391	0.398	0.866
	L.50-99 employees	0.174	0.175	0.977
	Age 0-15	0.326	0.311	0.682
	Age 16-30	0.388	0.396	0.828
	Located in eastern Germany	0.330	0.319	0.788
	Part of firm group	0.439	0.428	0.782
	L.Sales growth	0.087	0.088	0.968
	L.Mean innovation expenditures per employee	0.020	0.020	0.776
	L.Firm rating	217.652	219.285	0.659
2009	L.1-9 employees	0.109	0.108	0.967
	L.10-49 employees	0.405	0.412	0.882
	L.50-99 employees	0.158	0.158	0.994
	Age 0-15	0.278	0.277	0.977
	Age 16-30	0.416	0.416	0.991
	Located in eastern Germany	0.376	0.365	0.831
	Part of firm group	0.459	0.451	0.872
	L.Sales growth	0.113	0.086	0.688
	L.Mean innovation expenditures per employee	0.019	0.019	0.992
	L.Firm rating	218.945	218.930	0.998
2010	L.1-9 employees	0.107	0.105	0.907
	L.10-49 employees	0.397	0.408	0.762
	L.50-99 employees	0.167	0.162	0.857
	Age 0-15	0.283	0.280	0.917
	Age 16-30	0.432	0.429	0.927
	Located in eastern Germany	0.341	0.330	0.754
	Part of firm group	0.421	0.413	0.826
	L.Sales growth	-0.073	-0.074	0.970
	L.Mean innovation expenditures per employee	0.020	0.019	0.811
	L.Firm rating	220.296	220.276	0.995

References

Acemoglu, D., D. H. Autor and D. Lyle (2004), Women, war, and wages: The effect of female labor supply on the wage structure at midcentury, Journal of political Economy, 112(3), 497-551.

Acharya, V., and O. Merrouche (2012), Precautionary hoarding of liquidity and inter-bank markets: Evidence from the sub-prime crisis, Review of Finance, 1-54.

Acharya, V., and D. Skeie (2011), A model of liquidity hoarding and term premia in inter-bank markets, Journal of Monetary Economics, 58, 436–47.

Aghion, P., P. Askenazy , N. Berman, G. Cette and L. Eymard (2012), Credit Constraint and the Cyclicality of R&D Investment: Evidence from France, Journal of the European Economic Association, 10(5), 1001-1024.

Aghion, P. and P. Howitt (2009), The Economics of Growth. MIT Press, Cambridge, Mass.

Akerlof, G. A. (1970), “The Market for "Lemons": Quality Uncertainty and the Market Mechanism”, The Quarterly Journal of Economics, 84(3), 488-500.

Alessandrini, P., A. F. Presbitero, and A. Zazzaro (2010), Bank size or distance: what hampers innovation adoption by SMEs?, Journal of Economic Geography, 10(6), 845-881.

Amore, M. D., C. Schneider and A. Žaldokas (2013), Credit supply and corporate innovation, Journal of Financial Economics, 109(3), 835-855.

Amore, M.D. (2015), Companies learning to innovate in recessions, Research Policy 44(8), 1574–1583.

Archibugi D., A. Filippetti, and M. Frenz (2013a), Economic crisis and innovation: is destruction prevailing over accumulation?, Research Policy, 42(2):303–314.

Archibugi D., A. Filippetti, and M. Frenz (2013b), The impact of the economic crisis on innovation: evidence from Europe, Technological Forecasting and Social Change, 80(7), 1247–1260.

Ashcraft, A., J. McAndrews, and D. Skeie (2011), Precautionary reserves and the interbank market, Journal of Money, Credit and Banking, 43, 311–48.

Ayyagari, M., A. Demirgüç-Kunt, V. Maksimovic (2011), Firm innovation in emerging markets: the role of finance, governance and competition, Journal of Financial and Quantitative Analysis, 46, 1545–1580.

Barlevy, G. (2007), On the cyclicality of research and development, The American Economic Review, 97(4), 1131-1164.

Barras, R. (1986), Towards a theory of innovation in services, Research policy, 15(4), 161-173.

Behr, P., L. Norden, and F. Noth (2013), Financial constraints of private firms and bank lending behavior, Journal of Banking and Finance, 37(9), 3472-3485.

Benfratello, L., F. Schiantarelli and A. Sembenelli (2008), Banks and innovation: Microeconometric evidence on Italian firms, Journal of Financial Economics, 90(2), 197-217.

Bond, S., D. Harhoff and J. Van Reenen (2005), Investment, R&D and Financial Constraints in Britain and Germany, Annales d'Economie et de Statistique, 79/80, 435-462.

Brautzsch, H. U., J. Günther, B. Loose, U. Ludwig, and N. Nulsch (2015), Can R&D subsidies counteract the economic crisis?–Macroeconomic effects in Germany, Research Policy, 44(3), 623-633.

Bräuning, F. and F. Fecht (2016), Relationship lending in the interbank market and the price of liquidity, Review of Finance, 21(1), 33-75.

Brown, J. R., G. Martinsson and B. C. Petersen (2012), Do financing constraints matter for R&D?, European Economic Review, 56(8), 1512-1529.

Bundesbank (2009), Die Entwicklung der Kredite an den privaten Sektor in Deutschland während der globalen Finanzkrise, Monatsbericht, September 2009.

Cameron, A. C. and P. K. Trivedi (2009), Microeconometrics using stata, fifth edition, College Station, TX: Stata press.

Campello, M., J.R. Graham and C.R. Harvey, (2010), The real effects of financial constraints: evidence from a financial crisis. Journal of Financial Economics, 97, 470–487.

Carbo-Valverde, S., F. Rodriguez-Fernandez and G. F. Udell (2009), Bank market power and SME financing constraints, Review of Finance, 13(2), 309-340.

Chava, S., A. Oettl, A. Subramanian and K. V. Subramanian (2013), Banking deregulation and innovation, Journal of Financial Economics, 109(3), 759-774.

Chodorow-Reich, G. (2013), The employment effects of credit market disruptions: Firm-level evidence from the 2008–9 financial crisis, The Quarterly Journal of Economics, 129(1), 1-59.

Cingano, F., F. Manaresi and E. Sette (2016), Does Credit Crunch Investment Down? New Evidence on the Real Effects of the Bank-Lending Channel, Review of Financial Studies, 29(10), 2737-2773.

Cornaggia, J., Y. Mao, X. Tian and B. Wolfe (2015), Does banking competition affect innovation?, Journal of Financial Economics, 115(1), 189-209.

Cornett, M., J. McNutt, P. Strahan and H. Tehranian (2011), Liquidity risk management and credit supply in the financial crisis, Journal of Financial Economics, 101, 297–312.

Craig, B. and G. von Peter (2014), Interbank tiering and money center banks, Journal of Financial Intermediation, 23(3), 322-347.

Czarnitzki, D. and H. Hottenrott (2011a), Financial constraints: Routine versus cutting edge R&D investment, Journal of Economics & Management Strategy, 20(1), 121-157.

Czarnitzki, D. and H. Hottenrott (2011b), R&D investment and financing constraints of small and medium sized firms, Small Business Economics, 36(1), 65-83.

Czarnitzki, D., and A. A. Toole (2011), Patent protection, market uncertainty, and R&D investment, The Review of Economics and Statistics, 93(1), 147-159.

Duchin, R., Ozbas, O. and B. A. Sensoy (2010), Costly external finance, corporate investment, and the subprime mortgage credit crisis, Journal of Financial Economics, 97(3), 418-435.

Filippetti, A. and D. Archibugi (2011), Innovation in times of crisis: national systems of innovation, structure, and demand. Research Policy, 40(2), 179–192.

Freel, M. (2006), Patterns of technological innovation in knowledge-intensive business services, Industry and Innovation, 13(3), 335-358.

Freel, M. S., (2007), Are small innovators credit rationed?, Small Business Economics, 28(1), 23–35.

Gallouj, F., and O. Weinstein (1997), Innovation in services, Research policy, 26(4-5), 537-556.

Greene, W. H., (2003), Econometric Analysis, fifth edition, Prentice Hall, Upper Saddle River, NJ.

Grossman, G.M. and E. Helpman (1994), Endogenous innovation in the theory of growth, Journal of Economic Perspectives, 8(1), 23–44.

Hall, B. H. (2002), The Financing of Research and Development, Oxford Review of Economic Policy, 18(1), 35–51.

Hall, B. H. and J. Lerner (2010), The Financing of R & D and Innovation, In: Hall, B. H. and N. Rosenberg (Eds.), Handbook of the Economics of Innovation, Elsevier, North-Holland.

Hangoma, P., B. Robberstad and A. Aakvik (2017), Does Free Public Health Care Increase Utilization and Reduce Spending? Heterogeneity and Long-Term Effects, World Development, forthcoming (https://doi.org/10.1016/j.worlddev.2017.05.040).

Harhoff, D. (1998), Are There Financing Constraints for R&D and Investment in German Manufacturing Firms?, Annales d'Économie et de Statistique, 49/50, 421-456.

Harhoff, D. and T. Körting (1998), Lending relationships in Germany–Empirical evidence from survey data, Journal of Banking & Finance, 22(10), 1317-1353.

Himmelberg, C.P. and B.C. Petersen (1994), R&D and Internal Finance: A Panel Study of Small Firms in High-Tech Industries, Review of Economics and Statistics 76, 38-51.

Hottenrott, H., and B. Peters (2012), Innovative capability and financing constraints for innovation: More money, more innovation?, Review of Economics and Statistics, 94(4), 1126-1142.

Hsu, P. H., X. Tian and Y. Xu (2014), Financial development and innovation: Cross-country evidence, Journal of Financial Economics, 112(1), 116-135.

Hud, M., and K. Hussinger (2015), The impact of R&D subsidies during the crisis, Research Policy, 44(10), 1844-1855.

Imbens, G. W. and J. M. Wooldridge (2009), Recent developments in the econometrics of program evaluation, Journal of economic literature, 47(1), 5-86.

IMF (2016), Germany; Financial Sector Assessment Program-Systemic Liquidity and Bank Funding-Technical Notes, No 16/195, IMF Staff Country Reports, International Monetary Fund.

Ivashina, V. and D. Scharfstein (2010), Bank lending during the financial crisis of 2008, Journal of Financial Economics, 97(3), 319-338.

Iyer, R., J.-L. Peydró, S. da-Rocha-Lopes and A. Schoar (2014), Interbank Liquidity Crunch and the Firm Credit Crunch: Evidence from the 2007–2009 Crisis, Review of Financial Studies, 27(1), 347-372.

Kahle, K. M., and R. M. Stulz (2013), Access to capital, investment, and the financial crisis. Journal of Financial Economics, 110(2), 280-299.

Kapan, T. and C. Minoiu (2013), Balance Sheet Strength and Bank Lending During the Global Financial Crisis, Working Papers (No. 13/102), International Monetary Fund.

Lee, S., H. Sameen and M. Cowling (2015), Access to finance for innovative SMEs since the financial crisis, Research Policy, 44(2), 370-380.

López-García, P., J.M. Montero and E. Moral-Benito (2013), Business cycles and investment in productivity-enhancing activities: Evidence from Spanish Firms, Industry and Innovation, 20(7), 611-636.

Männasoo, K. and J. Meriküll (2014), R&D, Credit Constraints, and Demand Fluctuations: Comparative Micro Evidence from Ten New EU Members, Eastern European Economics, 52(2), 49-64.

Meriläinen, J. M. (2016), Lending growth during the financial crisis and the sovereign debt crisis: The role of bank ownership type, Journal of International Financial Markets, Institutions and Money, 41, 168-182.

Mina, A., H. Lahr and A. Hughes (2013), The demand and supply of external finance for innovative firms, Industrial and Corporate Change, 22(4), 869–901.

Mora, R. and I. Reggio (2015), didq: A command for treatment-effect estimation under alternative assumptions, The Stata Journal, 15 (3), 796-808.

Nanda, R. and T. Nicholas, (2014), Did bank distress stifle innovation during the Great Depression?, Journal of Financial Economics, 114(2), 273-292.

North, D., Baldock, R. and F. Ullah (2013), Funding the growth of UK technology-based small firms since the financial crash: are there breakages in the finance escalator?, Venture Capital, 15(3), 237–260.

Ouyang, M. (2011), On the Cyclicality of R&D. Review of Economics and Statistics, 93(2), 542-553.

Paunov, C. (2012), The global crisis and firms' investments in innovation, Research Policy, 41(1), 24–35.

Puri, M., J. Rocholl and S. Steffen (2011), Global retail lending in the aftermath of the US financial crisis: Distinguishing between supply and demand effects, Journal of Financial Economics, 100(3), 556-578.

Schumpeter, J. (1911), The Theory of Economic Development, Harvard University Press, Cambridge, MA.

Solow, R. M. (1957), Technical change and the aggregate production function, The review of Economics and Statistics, 39(3), 312-320.

Tether, B. S. (2005), Do services innovate (differently)? Insights from the European innobarometer survey, Industry & Innovation, 12(2), 153-184.

Waldinger, F. (2010), Quality matters: The expulsion of professors and the consequences for PhD student outcomes in Nazi Germany, Journal of Political Economy, 118(4), 787-831.

Yamamura, E. (2016), Impact of the Fukushima nuclear accident on obesity of children in Japan (2008–2014), Economics and Human Biology, 21, 110-121.