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Christian Grimme

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Uncertainty and the Cost of Bank vs. Bond Finance

Abstract

How does uncertainty affect the costs of raising finance in the bond market and via bank loans? Empirically, this paper finds that heightened uncertainty is accompanied by an increase in corporate bond yields and a decrease in bank lending rates. This finding can be explained with a model that includes costly state verification and a special informational role for banks. To reduce uncertainty, banks acquire additional costly information about borrowers. More information increases the value of the lending relationship and lowers the lending rate. Bond investors demand compensation for the increased risk of firm default.

JEL-Codes: E320, E430, E440, G210.

Keywords: uncertainty shocks, financial frictions, relationship banking, bank loan rate setting, information acquisition.

Christian Grimme
Ifo Institute – Leibniz Institute for Economic Research at the University of Munich
Poschingerstrasse 5
Germany – 81679 Munich
grimme@ifo.de

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1 Introduction

Is the cost of bank financing different from that of bond financing during periods of elevated uncertainty? In contrast to corporate bond holders, banks often form long-term relationships with their borrowers. Maintaining these relationships induces banks to lend at more favorable terms in response to changes in a firm's credit risk (see, e.g., Berlin and Mester, 1999; Petersen and Rajan, 1995). Sharpe (1991) argues that banks may continue to lend to troubled borrowers even at concessionary rates. Therefore, the costs of bond finance and those of bank loans may evolve differently during periods of heightened uncertainty.

This paper makes two contributions. First, using uncertainty proxies constructed from survey data, I document a new stylized fact for the United States and Germany: following a sudden hike in uncertainty, the cost of corporate bond finance increases, whereas bank loan rates decrease. Second, the reasons for the opposite reactions are explored by using a simple partial equilibrium model. The model features costly state verification and a special informational role for banks. In contrast to bond holders, banks maintain long-term relationships with their clients and are able to acquire costly information about borrowers. When uncertainty increases, banks collect additional information, which reduces uncertainty and the expected borrower default. This additional information makes the relationship even more valuable by strengthening the banks' information monopoly over the borrower in the future. Banks reduce lending rates to avoid jeopardizing the relationship.

A recent strand of the literature argues that uncertainty affects the real economy through financial frictions. Gilchrist, Sim, and Zakrajšek (2014) and Christiano, Motto, and Rostagno (2014) suggest that higher uncertainty about idiosyncratic productivity increases the probability of firm default. Due to limited liability, the risk premium on the cost of external financing rises. This link constitutes the risk compensation channel of uncertainty.[1] Gilchrist et al. (2014) provide empirical evidence for this channel for the United States using spreads derived from corporate bond yields.[2] However, many firms, particularly in the Euro Area, rely more heavily on banks than on the capital market for debt financing.[3]

[1]The interaction between uncertainty and different types of financial frictions is theoretically analyzed by Arellano, Bai, and Kehoe (2016), Bonciani and van Roye (2016), Cesa-Bianchi and Fernandez-Corugedo (2014), Chugh (2016), Dorofeenko, Lee, and Salyer (2008), Fendoglu (2014), Fernández-Villaverde (2010), Güntner (2015), and Hafstead and Smith (2012).

[2]For the United States, Popp and Zhang (2016) confirm that a rise in uncertainty widens the corporate bond spread. Caldara, Fuentes-Albero, Gilchrist, and Zakrajšek (2016) show that increases in uncertainty deteriorate financial conditions as measured by the excess bond premium. For Germany, Popescu and Smets (2010) demonstrate that higher uncertainty increases the common component of several risk premium indices.

[3]For Spain, Germany, and Italy, corporate bonds accounted for 2–13% of the total debt of nonfinancial corporations in 2015. For France and the United Kingdom, this figure is 22–26%, whereas for the United States it is 71%. In contrast, bank loans amount to 29% of firm debt in the United States and 74–98% in the five European countries (see also Figure 10 in Appendix A).

The novel contribution of this paper is to analyze the effects of idiosyncratic, that is, business, uncertainty on corporate bond yields and bank loan rates for the United States and Germany. Following the strategy of Bachmann, Elstner, and Sims (2013), the business uncertainty measures are constructed from the Philadelphia Fed's Business Outlook Survey (BOS) for the United States and from the ifo Business Climate Survey (ifo-BCS) for Germany. This is in contrast to Gilchrist et al. (2014), who rely on U.S. financial data.[4] The drawback of financial data is that they limit the analysis to large firms, whereas survey data encompass firms of all sizes, at least in the ifo-BCS. Furthermore, survey data are obtained from actual decision-makers at the firms in contrast to, for example, financial analysts (Bachmann et al., 2013). Using the survey data, business uncertainty is proxied by the cross-sectional dispersion of expectations about firms' future economic activity. To analyze the dynamic response of the two cost measures of external finance to surprise movement in uncertainty, vector autoregression (VAR) models are employed. The results show that corporate bond yields increase, whereas bank loan rates fall, as uncertainty increases. This contrasting behavior is found for both the United States and Germany. A number of robustness checks confirm this result.

Why do the costs of bank finance decrease in periods of heightened uncertainty whereas those of bond finance increase? To answer this question, I develop a partial equilibrium model that features costly state verification (CSV) and a special informational role for banks. Firms finance their projects by obtaining bank loans or issuing bonds. There are two types of informational problems: (i) information is asymmetrically distributed between borrowers and lenders, and (ii) the outcome of a firm's project is ex-ante uncertain to both the borrower and the lender. Following Rossi, Sekhposyan, and Soupre (2016), uncertainty about the project stems from both risk and ambiguity (Knightian uncertainty). An increase in risk increases the dispersion of the distribution. Higher ambiguity makes it harder to correctly assign probabilities to each possible event.

In contrast to bond investors, banks are able to at least partially overcome both types of informational problems. First, through continuous interactions with the customers, banks acquire private information and reduce informational asymmetries over time (see, e.g., Boot, 2000). Banks obtain an informational advantage over other, uninformed lenders, and they can charge a markup on the loan rate in later periods due to monopoly power (see, e.g., Greenbaum, Kanatas, and Venezia, 1989; Rajan, 1992; Sharpe, 1990). This is the

[4]To derive a measure for idiosyncratic uncertainty, Gilchrist et al. (2014) use daily stock returns for U.S. nonfinancial corporations. In a first step, they remove the forecastable variation in idiosyncratic excess returns. In a second step, they compute the quarterly firm-level standard deviation of the estimated residuals from the first step. In a third step, they assume that this standard deviation follows an AR(1) process with firm fixed effects, a firm-specific term, and time fixed effects. The series of time fixed effects is used as an aggregate proxy for idiosyncratic uncertainty.

long-term benefit of collecting private information. Second, banks can spend resources to collect additional market information in order to reduce the ambiguous component of the projects' return distribution and then share this information with their borrowers. This is the short-term benefit of acquiring market information. This additional market information encompasses more than what is publicly available, and can include, for example, information about the market in which the firm operates gleaned from talking to other customers active in the same sector or by having the bank's economic department conduct in-depth market analyses. Market information does not affect the risky component of the return distribution, however. As with private information, market information facilitates the lender's continuation or liquidation of the project in the event of borrower default. A future default becomes less costly and banks can charge higher loan rates in later periods. This is the long-term benefit of collecting market information.

Banks can counteract an increase in uncertainty by collecting additional costly market information, which has two effects. First, it reduces the ambiguous component. Subsequently, the increase in the expected probability of borrower default and in the lending rate is attenuated. Second, as a side effect, additional market information increases the value of the customer-bank relationship via higher future markups due to lower costs of borrower default. The bank's incentive to prevent the borrower from defaulting during the period of elevated uncertainty becomes stronger, and thus the bank lowers the lending rate during this time. Together, the two effects constitute the information channel of uncertainty. This channel puts downward pressure on the lending rate in times of heightened uncertainty.

The bank loan rate's response to sudden changes in uncertainty is determined by both the risk compensation and the information channels. If the sum of the short-term advantage of lower uncertainty and the long-term benefit of continuing the relationship are larger than the short-term gain of being adequately compensated for the increased risk, banks lower the lending rate. If the gains from risk compensation are stronger than those from acquiring additional information, bank loan rates increase. In contrast, bond investors have only publicly available information and are not specialized in collecting private or additional market information (see, e.g., Rajan, 1992). When uncertainty rises, the cost of corporate bonds is determined only by the risk compensation channel, and market debt always becomes more expensive.

This paper is the first to analyze the link between idiosyncratic uncertainty and the costs of bank loans. Several contributions in the literature look at the effects of aggregate uncertainty on the supply of bank loans (Alessandri and Bottero, 2017; Bordo, Duca, and Koch, 2016; Buch, Buchholz, and Tonzer, 2015; Raunig, Scharler, and Sindermann, forthcoming; Valencia, 2013), finding that increases in uncertainty have a negative effect on bank lending. However, they also document that the negative relationship is mostly driven by banks that are less capitalized or have low liquidity buffers. These results do not contradict the findings of this paper. Poorly capitalized banks reduce lending when uncertainty increases and are less concerned with long-term strategies such as maintaining relationship lending. In contrast, highly capitalized banks can continue to lend to borrowers with relatively uncertain prospects without raising the probability of bank default due to their capital buffer. These banks acquire additional information when uncertainty rises, the value of relationship lending rises, and uncertainty falls, and they continue to lend to both safer and riskier borrowers at lower rates.

Section 2 presents the construction of the business uncertainty proxies and describes the measures for the costs of external finance. Section 3 empirically investigates the effects of uncertainty shocks on corporate bond yields and bank loan rates; robustness checks are also presented. Section 4 provides context for the empirical results using a partial equilibrium model. Section 5 concludes.

2 Measuring Uncertainty and the Costs of External Finance

This section presents the construction of the proxies for business uncertainty and describes the series that reflect the costs of external finance.

I follow Bachmann et al. (2013) and use business survey data to construct the business uncertainty proxies for the United States and Germany. For the United States, I use data from the BOS, which is conducted monthly by the Federal Reserve Bank of Philadelphia. The uncertainty proxy $FDISP^{US}$ is the dispersion of firms' forecasts about the general business outlook.[5] For Germany, I rely on manufacturing firms' responses to the ifo-BCS (IBS-IND, 2017), which is conducted on a monthly basis. The uncertainty proxy $FDISP^{GER}$ is calculated as the cross-sectional dispersion of expectations about future production. Bachmann et al. (2013) show that both uncertainty measures are countercyclical and positively correlated with other (business) uncertainty proxies.

The reason for using business uncertainty instead of other uncertainty proxies is that according to theoretical models by Gilchrist et al. (2014) and Christiano et al. (2014), a firm's financial condition is affected by idiosyncratic uncertainty. This type of uncertainty is defined as the ex-ante volatility of firm-level shocks, and this volatility is common to all firms. Therefore, proxies for business uncertainty link the empirical part of this paper as closely as possible to existing theoretical models. In contrast, measures of policy uncertainty

[5] A more detailed description of the construction of the proxies is presented in Appendix B.

or macroeconomic uncertainty cover other or broader aspects of uncertainty (see, e.g., Baker, Bloom, and Davis, 2016; Jurado, Ludvigson, and Ng, 2015) and, therefore, are not used in this paper.

For the cost measure of bank finance for the United States, I take the loan rate of commercial and industrial loans with an initial interest rate fixation of up to one year.[6] This series is part of the Survey of Terms of Business Lending (STBL) and is collected quarterly from a random sample of about 300 U.S. banks (Brady, English, and Nelson, 1998); it is available for the period Q2:1997 to Q2:2017. Loans with a maturity of up to one year cover more than 90% of all commercial and industrial loans in the United States. For Germany, I use the loan rate of new loans to nonfinancial corporations in Germany with an initial interest rate fixation of up to one year.[7] This series is part of the MFI interest rate statistics and is collected monthly by the Deutsche Bundesbank from a representative sample of 200–240 banks in Germany. Loans with a maturity of one year cover more than 80% of all new loans to nonfinancial corporations. This series is available only from January 2003, which is when the national interest rate statistics of all countries in the Eurozone were harmonized. I link the series to the discontinued loan rates on medium and long-terms loans to enterprises obtained from the Deutsche Bundesbank in order to extend the series back to November 1996.

For the cost measure of bond finance for the United States, I use the corporate bond yield for maturities between one and three years. The yield tracks the performance of outstanding bonds issued by investment-grade U.S. corporations. For Germany, I rely on yields from outstanding bonds issued by German nonfinancial corporations. These include securities with a maturity of more than four years. The average maturity of these bonds is 5.8 years in the period 1997–2015.[8] To my knowledge, other indexes are not available due to the relatively small market for German corporate bonds.

Figure 1 plots the time series of the uncertainty proxies, corporate bond yields, and bank lending rates for the United States and Germany between 1997 and 2017. For illustrative purposes, the monthly series are averaged to a quarterly frequency. The uncertainty measures are demeaned and normalized by their standard deviation. The upper two panels show the uncertainty proxies and the corporate bond yields for the two countries. Uncertainty and the corporate bond yield co-move in the United States; the correlation coefficient is 0.52. In Germany, periods during which bond yields and uncertainty co-move alternate with periods

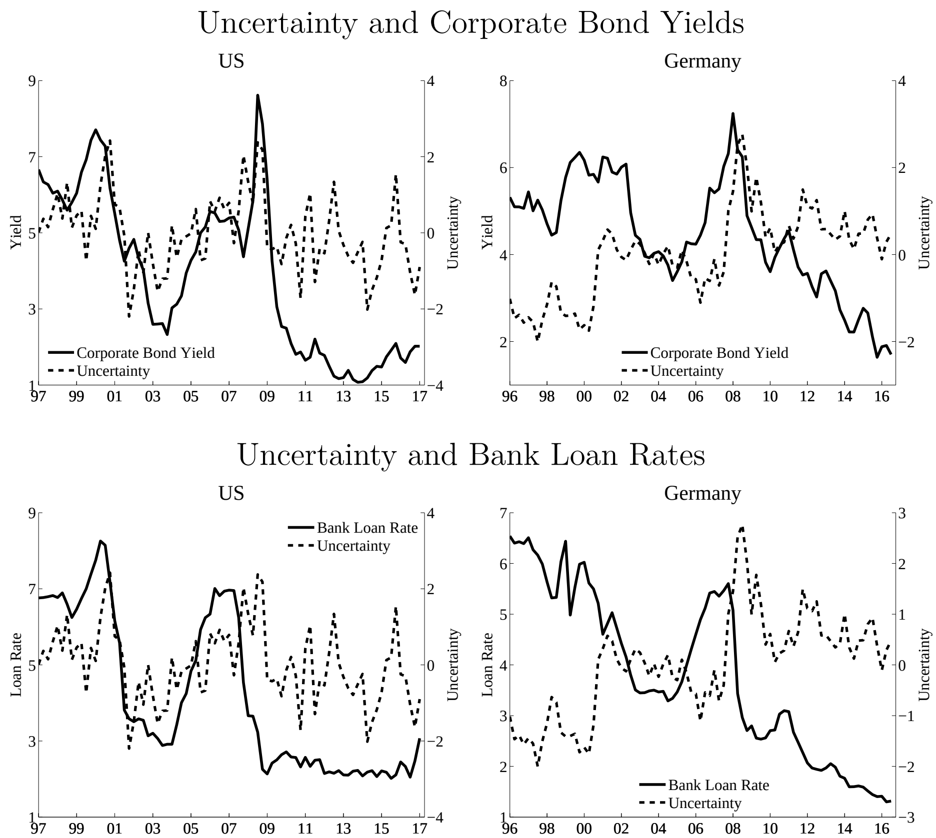
[6]The rate is constructed as the volume-weighted average of the rates of loans with a repricing interval of zero, daily, 2 to 30 days, and 31 to 365 days. For the sample period, the volume-weighted average maturity of these loans is 430 days, which is a bit longer than a year. Therefore, I associate bank loans with a maturity of one year and use the expressions "repricing interval" and "maturity" interchangeably throughout the paper.

[7]To arrive at this rate, I compute the volume-weighted average of the rates of new loans below 1 million and above 1 million Euro.

[8]I thank Anja Huck from the Deutsche Bundesbank for providing this information.

during which the two series move in opposite directions. Overall, they are negatively correlated (-0.28). The lower two panels plot the uncertainty proxies and the bank loan rates. The correlation between uncertainty and the lending rate is positive in the United States; the coefficient is 0.43. In Germany, the two series are negatively correlated with a coefficient of -0.71.

Figure 1: Uncertainty and the Costs of Bank and Bond Finance



Notes: The figure shows the quarterly averages of the monthly time series, except for the U.S. loan rate, which is originally at a quarterly frequency. The uncertainty proxy for the United States, $FDISP^{US}$, is from the BOS; that for Germany, $FDISP^{GER}$, from the ifo-BCS. Both uncertainty proxies are standardized. The sample period is 1997:Q2–2017:Q2 for the United State and 1996:Q4–2017:Q2 for Germany.

3 Empirical Evidence

Subsection 3.1 presents the results from the baseline VARs. These small-scale models focus on the responses of corporate bond yields and bank loan rates to surprise increases in uncertainty. Subsection 3.2 provides a number of robustness checks, for which the VAR models are extended to include additional control variables.

3.1 Baseline Results

Two VARs are estimated for each country. The baseline VARs consist of three variables: a proxy for uncertainty, a measure for the cost of external finance, and the government bond yield as a measure for the riskless rate.[9] The cost of external finance is either the yield on corporate bonds or the bank loan rate.[10] Due to the quarterly frequency of the U.S. loan rate series, this series is interpolated with the monthly available prime rate as an interpolator variable using the Chow-Lin procedure.[11] The prime rate is the rate charged by the majority of the largest 25 U.S. commercial banks on many of their (short-term) commercial loans and is an indicator for many other loan rates. At a quarterly frequency, the prime rate and the loan rate from the STBL are highly correlated; the correlation coefficient is 0.99. In all VAR models, the riskless rate is the one-year government bond yield of the respective country, with the exception of the model with the German corporate bond yield: this yield has an average maturity of roughly six years, so that the corresponding government bond yield has a six-year maturity.[12]

The sample period is from 1997:M4 to 2017:M6 for the United States and from 1996:M11 to 2017:M6 for Germany, the slight difference being due to the different availability of loan rate data in the two countries. The VARs are at a monthly frequency and estimated with a constant and a linear trend. The lag length is set to three in all models.[13] Uncertainty is ordered before the interest rate variables in a recursive identification. Innovations in uncertainty, therefore, have an immediate impact on the interest rate variables. Following Leduc and Liu (2016), this ordering can be justified by the fact that survey respondents to the BOS (ifo-BCS) answer by the first week of month t (by the middle of month t). Therefore, they do not have complete information about interest rates in month t and the information set contains only realizations of interest rates up to month $t-1$. In the following, I consider unit shocks to the standardized uncertainty series to ensure that possible differences in the impulse responses between the United States and Germany can be traced back to differences in the transmission mechanism and are not due to differences in the shock size.

Figure 2 plots the impulse responses from the four separate VARs for the United States and Germany after an innovation to $FDISP^{US}$ and $FDISP^{GER}$, respectively. The results

[9] Appendix C provides a short summary of all the variables used in the paper.

[10] For the United States, the yield on corporate bonds includes bonds with a maturity between one and three years. I rely on this type of maturity so as to be as close as possible to the maturity of bank loans.

[11] Using the original quarterly series in a quarterly VAR yields similar results (see Panel (a) in Figure 11 in Appendix D).

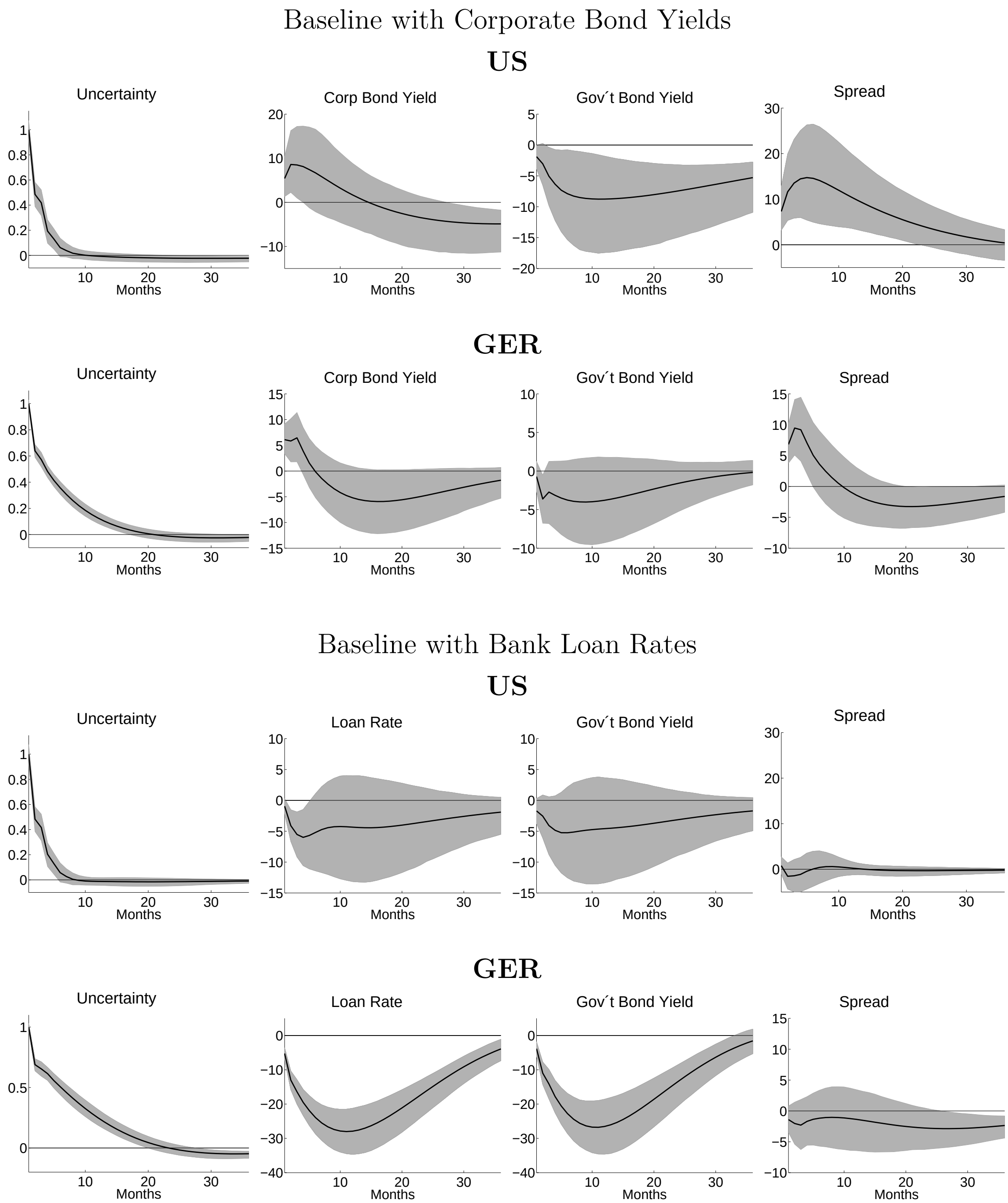
[12] Since the corporate bond yield for the United States includes maturities between one and three years, the baseline model is alternatively estimated with the U.S. government bond yield with a three-year maturity, which leads to quantitatively similar results (see Figure 12 in Appendix D).

[13] The BIC criterion suggests between one and two lags for the different models; the AIC criterion between two and 10 lags. Therefore, a lag length of three falls in the middle of these suggested values.

for the United States are shown in the first and third rows; the second and fourth rows contain results for Germany. The responses in the first two rows are based on the models with corporate bond yields. The impulse responses of the spread variables are calculated as the difference between each of the responses of the cost of external finance and the riskless rate. In both countries, the yields on corporate bonds and government bonds move in opposite directions. The government bond yields decrease, reaching a minimum after 8 to 12 months, signaling an increase in demand for government bonds consistent with a flight to safety. In contrast, the corporate bond yields increase. In the United States, the cost of corporate bond finance reaches a peak of about 10 basis points after two months, in Germany the maximum is around 7 basis points after two months. The yield reverts back more slowly in the United States than it does in Germany. The spread between the corporate bond yield and the riskless rate rises in both countries. The spreads increase by 7 basis points on impact, respectively, and reach a maximum of around 15 basis points after four months in the United States and after one month in Germany (10 basis points). The following decreases are more gradual in the United States than in Germany.

The responses based on the models with bank loan rates are shown in the last two rows of Figure 2. In both countries, the bank loan rates and government bond yields move in the same direction. In the United States, the loan rate reaches its minimum of −6 basis points after four months and returns to equilibrium relatively gradually. Loan rates in Germany fall for a year and revert back slowly. The minimum amounts to roughly −30 basis points. The spread between the bank loan rate and the riskless rate does not change significantly in either the United States or Germany.

Figure 2: Impulse Responses to Uncertainty Shock for the United States and Germany



Notes: Effects of a unit shock to the standardized uncertainty series $FDISP^{US}$ and $FDISP^{GER}$, respectively. Uncertainty is expressed in unit values; all other variables are expressed in basis points. Monthly VARs are estimated with three variables. Uncertainty is ordered first in a recursive identification. Responses in rows 1 and 2 are estimated with corporate bond yields, those in rows 3 and 4 with bank loan rates. Impulse responses of the spread variables are calculated as the difference between each of the responses of the cost of external finance and the riskless rate. Sample period is from 1997:M4–2017:M6 for the United States and 1996:M11–2017:M6 for Germany. Black solid lines depict the point estimates, shaded areas represent the 95% confidence intervals based on 5,000 bootstrap replications.

3.2 Robustness

The results from the baseline model reveal that an unexpected increase in uncertainty leads to an increase in corporate bond yields and a decline in bank lending rates. Therefore, the costs of bank and bond finance diverge in times of heightened uncertainty. I now conduct a battery of robustness checks that can be classified into three blocks: (i) features of the loan contract, (ii) substitution effects, and (iii) controlling for the macroeconomic environment.

3.2.1 Other Features of the Loan Contract

The first robustness check deals with the issue that bank loan contracts are usually characterized by both price and non-price characteristics, the later includes features like collateral requirements, covenants, and the loan's maturity. Instead of increasing loan rates in uncertain times, banks may impose higher lending standards. Data on lending standards are from the Senior Loan Officer Survey (SLOOS) for the United States.[14] I use the average of the net percentage of domestic banks increasing collateral requirements, tightening loan covenants, and reducing the maximum maturity of loans – for small, middle, and large firms. To include this measure in the monthly VAR, the series is linearly interpolated to a monthly frequency.[15] Lending standards are ordered after uncertainty. Panel (a) in Figure 3 shows that banks do not raise lending standards in response to increased uncertainty.

Some loans are extended under a previous commitment, that is, a loan may be drawn under a credit line. The terms of the credit line were negotiated in the past and, therefore, current loan rates only reflect past expectations about current developments. For Germany, this does not pose a problem as the loan rate series used so far encompasses only new loan agreements in which terms are agreed on for the first time (see Deutsche Bundesbank, 2004). In contrast, the U.S. loan rate series includes draw-downs.[16] Therefore, in this robustness check for the United States, the loan rate is replaced by the loan rate series on loans that are made under no previous commitment. Since these loans have, on average, a lower maturity, the corresponding riskless rate is now a three-month government bond yield. Panel (b) in Figure 3 shows that the loan rate of uncommitted loans falls in response to a sudden hike in uncertainty, and the spread remains constant.

Instead of changing loan rates, banks could react to heightened uncertainty by reducing the volume of new loans. Data on loan volumes are obtained from the STBL for the United

[14] For Germany, data on lending standards are, in principle, available from the Bank Lending Survey (BLS). However, these data are available only since 2003, which would reduce the sample size considerably. Therefore, in this exercise, I concentrate the analysis on the United States.

[15] The results remain unchanged when the VAR is estimated at a quarterly frequency (see Panel (b) in Figure 11 in Appendix D).

[16] I thank an anonymous referee for this point.

States and from the Deutsche Bundesbank for Germany. For the United States, the quarterly loan volumes are linearly interpolated to a monthly frequency.[17] Volumes are ordered after uncertainty. Panel (c) in Figure 3 shows that the loan rate falls in response to a sudden hike in uncertainty, and the spread remains constant. Two things are notable about the reaction of loan volumes. First, they do not fall for the first few months. Therefore, banks do not cut back on their lending immediately after uncertainty increases. Second, only after three to six months do new loans start to decrease by a maximum of 0.1 to 0.2 standard deviations. Thus, over time, banks react with respect to the loan amount, which is consistent with results from the literature on the effects of uncertainty on loan supply using panel regressions (Alessandri and Bottero, 2017; Bordo et al., 2016; Buch et al., 2015; Raunig et al., forthcoming; Valencia, 2013). One interpretation of this finding is that banks try to maintain relationships with all their borrowers at first. Only over time do banks start to reduce lending to some of their borrowers. This hypothesis is further analyzed below.

3.2.2 Substitution Effects

This section deals with two other possible explanations for why loan rates fall and corporate bond yields increase. First, firms may switch from loans to bonds. Second, banks may change the composition of their loan portfolio.

Firms may shift from bank to bond finance in uncertain times. During the financial crisis of 2007–2009, a time when corporate bond yields increased more than bank loan rates, Adrian, Colla, and Shin (2013) find that bank lending declined and firms shifted toward the capital market for financing. De Fiore and Uhlig (2015) argue that the cost of market finance rose because the average default risk of the pool of bond-financed firms increased. The cost of bank finance increased, albeit to a lesser extent than bond yields, even though firms with a high risk of default stopped borrowing from banks. This was because firms with intermediate risk switched from bank to bond finance. The question arises as to whether this phenomenon, which was a result of multiple shocks during a large-scale financial crisis, may also occur when smaller-scale uncertainty shocks hit the economy. The VARs in this exercise now include both the loan rate and the corporate bond yield next to loan and corporate bond volumes; the latter two are standardized.[18] Because of the large set of variables, the VARs are estimated

[17]When the VAR is estimated at a quarterly frequency the loan volume does not fall (see Panel (c) in Figure 11 in Appendix D).

[18]As the corporate bond yield and the loan rate in Germany have different maturities, the German VAR includes two riskless rates (government bond yields with a maturity of one year and of six years).

with Bayesian techniques in the form of a Minnesota-type prior. For the uncertainty series, I impose the prior belief of white noise; for the other variables, that of a random walk.[19]

Figure 4 shows that the impulse responses of the interest rates are similar to the baseline results in both countries. The costs of bond finance increase by 5 to 10 basis points and those of bank finance decrease by 5 to 20 basis points. The volume of corporate bonds does not change in reaction to uncertainty. Bank loans do not fall significantly for half a year (U.S.) to a year (Germany) after the shock. Afterward, they decrease by 0.05 and 0.15 standard deviations in the United States and Germany, respectively. This drop, albeit economically relatively small particularly in the United States, is persistent.

Two conclusions can be drawn from these observations. First, there is no evidence of substitution between loans and bonds conditional on an uncertainty shock. The effect of debt substitution during the Financial Crisis of 2008/09 found by other papers is probably the result of several large-scale shocks. An uncertainty shock by itself does not result in this type of behavior. Second, confirming the finding from the previous exercise, in the first periods after a sudden change in uncertainty, banks do not cut back on new loans. Only over time do banks start to reduce lending to a small extent.

The previous two checks show that bank lending does not react to an uncertainty shock immediately, but does do so to a small extent over time. This issue is now explored in greather depth. In general, the average bank loan rate may fall because the composition of borrowers in a bank's loan portfolio changes (see, e.g., Gilchrist and Mojon, forthcoming). Following an increase in uncertainty, banks may prefer to reduce the share of risky borrowers in their portfolios. The heterogeneity in borrowers' risk profiles should also lead to different responses by the respective lending rates. Compared to the riskless rate, the cost of riskier loans should increase by a larger amount than that of relatively riskless loans so that the lender is adequately compensated. Therefore, one should observe a larger increase in the loan rate spreads of riskier loans than in those of safer loans. The STBL data provide loan rates and volumes separately for different borrower types. In the survey, banks report risk ratings for their loans. Loans are classified as having either minimal, low, moderate, or acceptable risk.[20] For each risk category, a separate VAR is now estimated.

Figure 5 plots the impulse responses to an uncertainty shock of the loan quantities and the loan rates for each of the four risk categories. The lending rates fall across all risk categories. Quantitatively, the decrease is very similar. Likewise, the spread does not react significantly

[19]Resorting to employing the notation of Banbura, Giannone, and Reichlin (2010), the hyperparameter δ_{unc} for uncertainty is set to 0, the hyperparameters for the other variables are equal to 1. The hyperparameter λ is calibrated to 0.25, which is in line with Banbura et al. (2010), who set λ to 0.262 in a VAR with seven variables. The impulse responses are computed by generating 5,000 draws from the posterior.

[20]Brady et al. (1998) provide precise definitions for the risk classifications.

for any of the four risk types. The loan volumes do not react on impact. Over time only the amount of new loans made to borrowers with moderate risk falls by 0.1 standard deviations, while the loan quantities made to borrowers with higher risk ("acceptable") and of lower risk ("minimal" and "low") do not change significantly. So, banks do cut back on their lending to one type of borrower, albeit only over time. However, note that the size and direction of changes in loan rates and spreads do not vary with the riskiness of the borrowers. Even borrowers of higher risk are charged lower rates when uncertainty increases. Although there is evidence that banks change the composition of borrowers to a small extent over time after a sudden increase in uncertainty, risk shifting cannot explain the similar decline in loan rates for borrowers of different riskiness.[21]

On a final note, there is evidence in the literature that the impact of uncertainty on lending behavior varies with some bank characteristics, particularly with the degree of bank capitalization (Alessandri and Bottero, 2017; Bordo et al., 2016; Buch et al., 2015; Raunig et al., forthcoming; Valencia, 2013). Therefore, the finding in this paper that lending to borrowers with moderate risk falls may be mostly driven by poorly capitalized banks.

3.2.3 Macroeconomic Environment

To this point, the VAR models include only those variables that are directly linked to the loan contract or the bond market. This is a parsimonious way to model the joint dynamics of uncertainty and the costs of external finance. The current robustness check extends the baseline VARs to include three more macroeconomic variables: log of industrial production, log of consumer prices, and a measure of monetary policy. Production is included to control for real activity and the associated loan demand. Monetary policy for the United States is proxied by the effective Fed Funds Rate until 2008 and after 2015 and by the shadow rate in between (Wu and Xia, 2016) to account for the central bank's unconventional policies. For Germany, the EONIA is used before 2009 and the shadow rate afterward (Wu and Xia, 2017). Since the set of variables is relatively large, the VARs are estimated with Bayesian techniques, as previously described. For the three new variables, a prior belief of a random walk is assumed. Figure 6 shows that the previous findings do not depend on the dimension of the estimated VARs: corporate bond yields increase and bank loan rates decrease following a sudden rise in uncertainty.

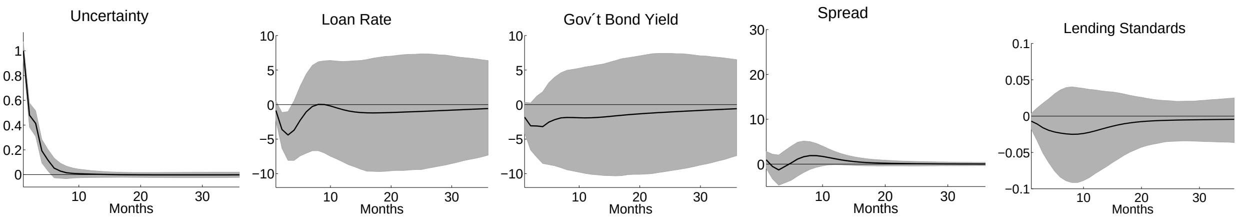
[21] Another possible explanation for why lending rates do not increase during periods of elevated risk involves adverse selection or moral hazard. Banks may be reluctant to raise interest rates because this may shift the composition of their loan portfolios toward borrowers with riskier projects (adverse selection) or because they fear that borrowers will switch to riskier projects (moral hazard). Appendix E analyzes these two arguments. The conclusion is that banks raise loan rates regardless of whether risk increases for all types of borrowers and for all types of projects. Therefore, the presence of adverse selection or moral hazard cannot explain why lending rates fall when risk increases.

Another concern is that the sample period encompasses the global financial crisis, which may have led to a structural break. To address this concern, the sample is estimated only up to August 2008. This poses some problems with respect to the sample length. My strategy is to focus on the debt type that is most prevalent in each country, so that the debt costs (i) are derived from a sufficient number of transactions as is the case for the U.S. corporate bond market (as opposed to the less liquid German market) or (ii) are officially released at a relatively high frequency as is the case for the German bank loan rate (compared to the quarterly collected U.S. bank loan rate). Furthermore, for the United States, I use the 30-year Baa-rated corporate bond yield together with the 30-year government bond yield to extend the sample backward. The estimation thus starts in May 1968 – the starting period of the BOS. For Germany, I estimate the original bank model starting in November 1996 using Bayesian methods to mitigate the sample length problem. Figure 7 shows that the corporate bond yields still increase and bank loan rates still decrease in response to heightened uncertainty.

Figure 3: Robustness I

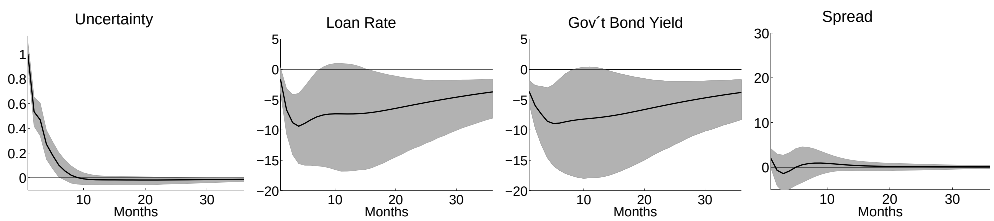
(a) Lending Standards

US



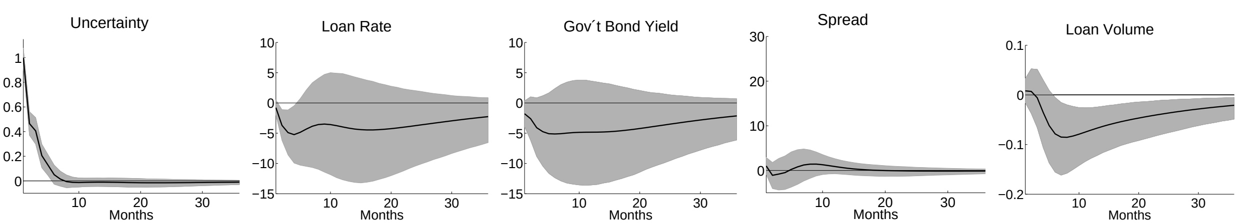
(b) Loans Not Under Commitment

US

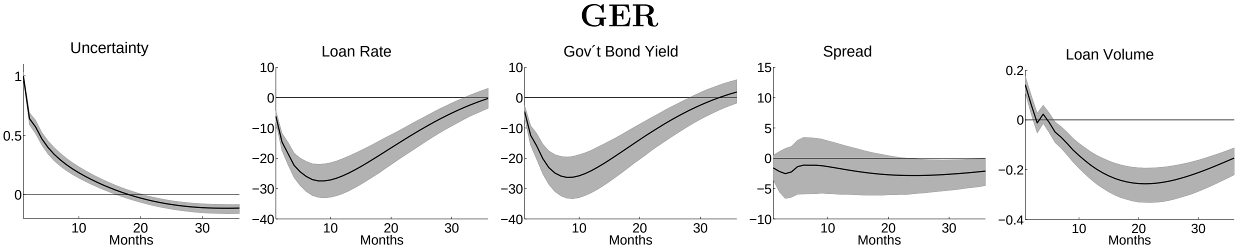


(c) Loan Volumes

US



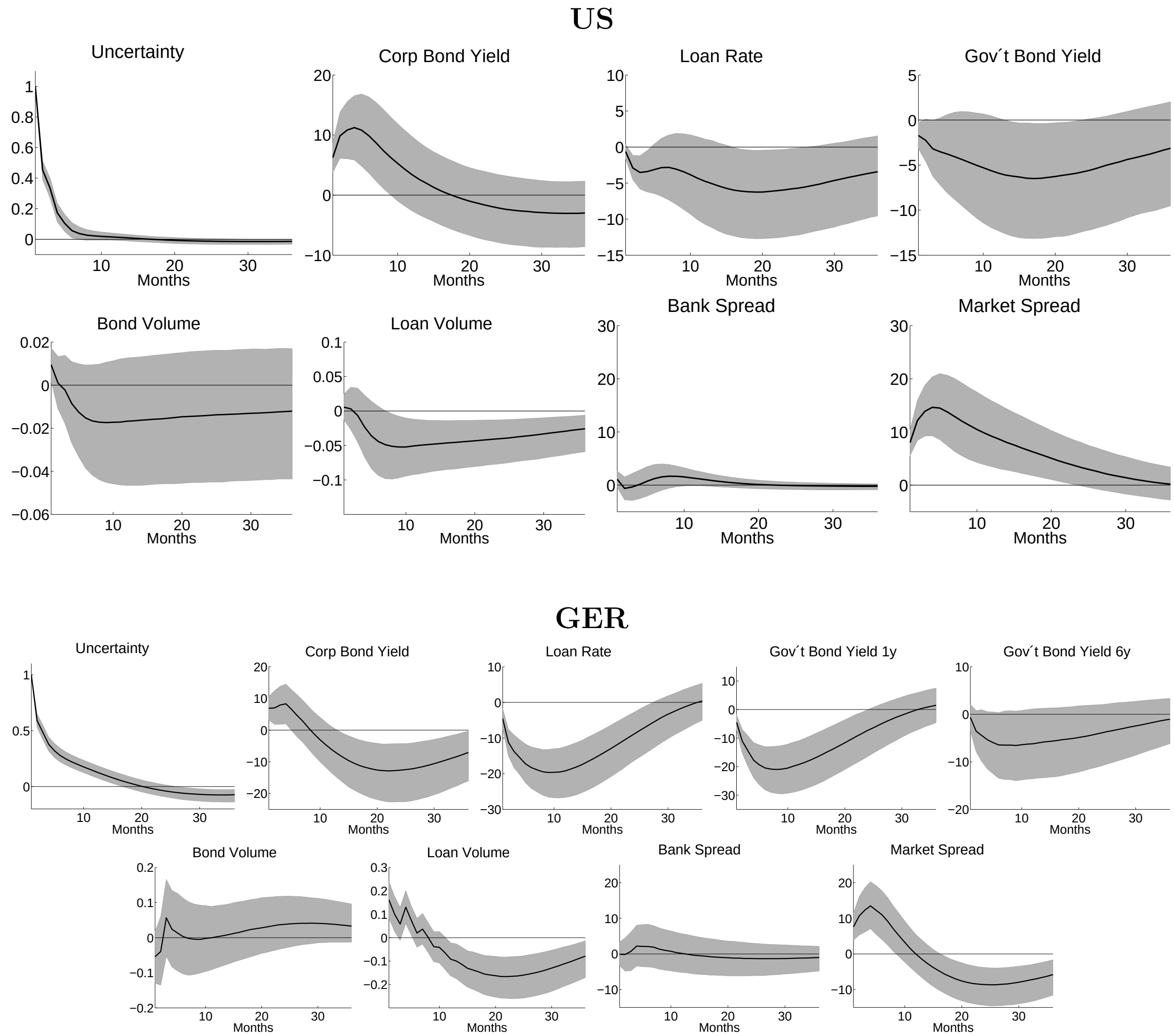
GER



Notes: Effects of a unit shock to the standardized uncertainty series $FDISP^{US}$ and $FDISP^{GER}$, respectively. Uncertainty is expressed in unit values, lending standards and loan volumes in standard deviations; all other variables are expressed in basis points. Panels (a) and (c): Monthly VAR is estimated with four variables. Panel (b): Monthly VAR is estimated with three variables. Uncertainty is ordered first in a recursive identification. Responses in rows 1, 3, and 4 are estimated with the baseline bank loan rate, those in row 2 with loan rates of loans not under commitment. Impulse responses of the spread variables are calculated as the difference between each of the responses of the bank loan rate and the riskless rate. Panel (a): Sample period is from 1997:M4–2017:M6. Panel (b): Sample period is from 2003:M5–2017:M5. Panel (c): Sample period is from 1997:M5–2017:M5 for the United States and from 1996:M11–2017:M6 for Germany. Black solid lines depict the point estimates, shaded areas represent the 95% confidence intervals based on 5,000 bootstrap replications.

Figure 4: Robustness II

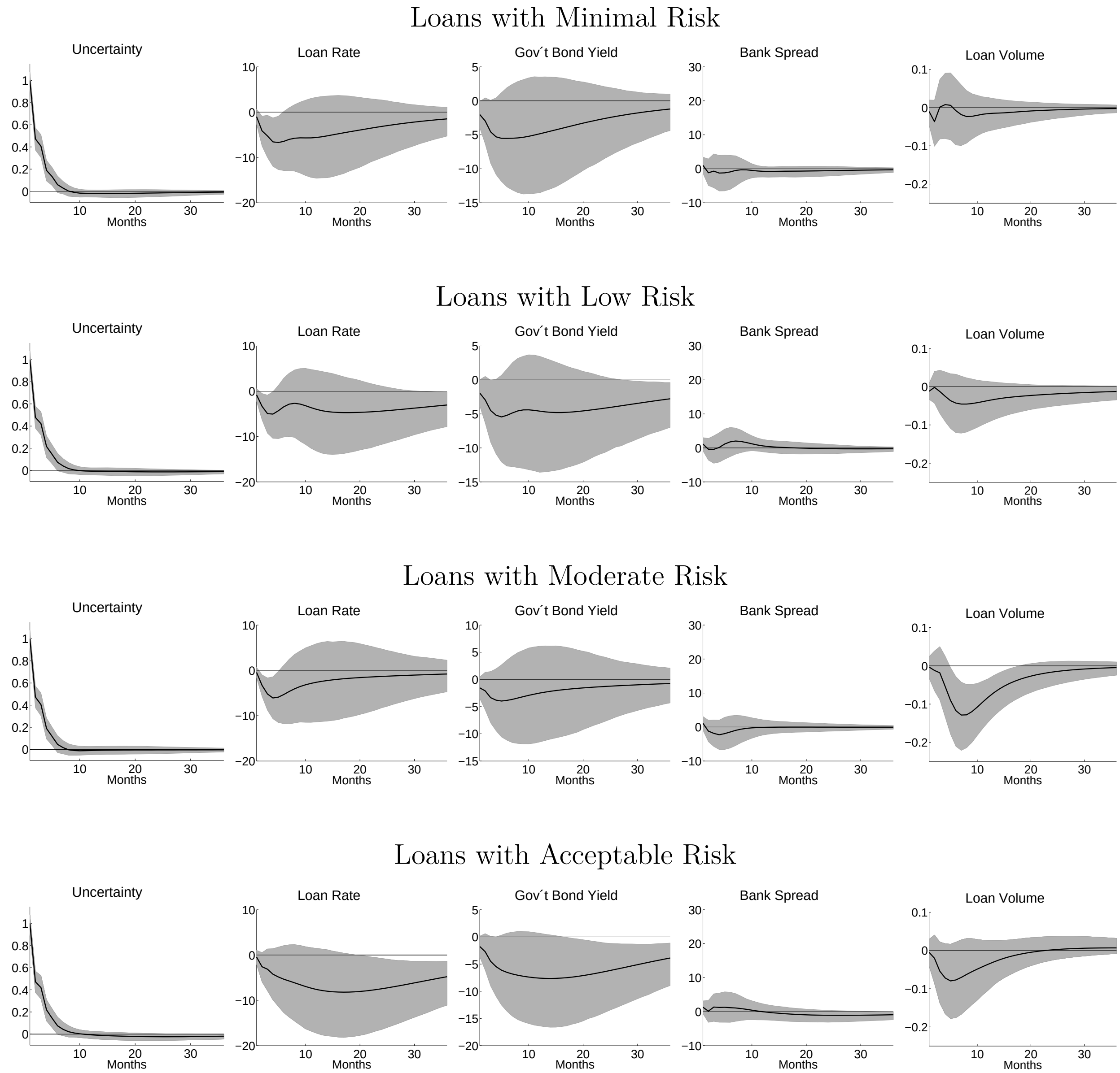
Interaction Between Corporate Bonds and Bank Loans



Notes: Effects of a unit shock to the standardized uncertainty series $FDISP^{US}$ and $FDISP^{GER}$, respectively. Uncertainty is expressed in unit values, loan and bond volumes are expressed in standard deviations; all other variables in basis points. Monthly VARs are estimated with six variables for the United States and seven variables for Germany; both models are estimated with Bayesian techniques. Models include corporate bond yields and bank loan rates. Uncertainty is ordered first in a recursive identification. Impulse responses of the spread variables are calculated as the difference between each of the responses of the cost of external finance and the riskless rate. Sample period is from 1997:M9–2017:M5 for the United States and 1996:M11–2017:M6 for Germany. Black solid lines depict the median responses, shaded areas represent 68% error bands.

Figure 5: Robustness III

US

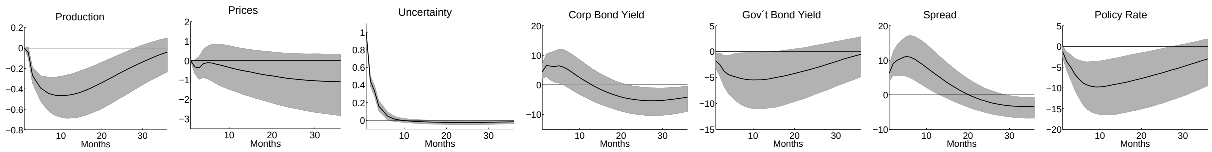


Notes: Effects of a unit shock to the standardized uncertainty series $FDISP^{US}$. Uncertainty is expressed in unit values, loan volumes are expressed in standard deviations; all other variables in basis points. Monthly VARs are estimated with four variables. Uncertainty is ordered first in a recursive identification. Responses in row 1 are estimated with loan rates for borrowers with minimal risk, in row 2 with low risk, in row 3 with moderate risk, and in row 4 with acceptable risk. Impulse responses of the spread variables are calculated as the difference between each of the responses of the loan rate and the riskless rate. Sample period is from 1997:M5–2017:M5. Black solid lines depict the point estimates, shaded areas represent the 95% confidence intervals based on 5,000 bootstrap replications.

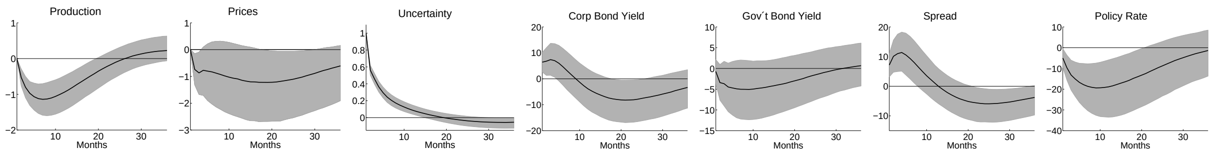
Figure 6: Robustness IV

With Corporate Bond Yields and Macro Variables

US

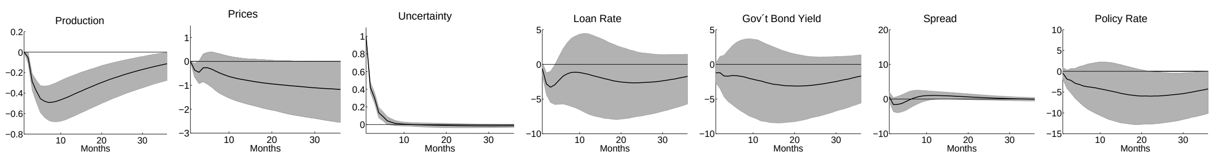


GER

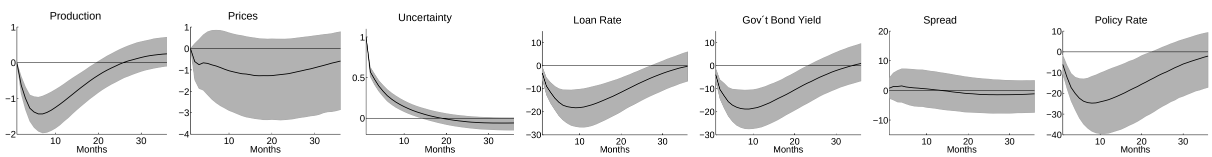


With Bank Loan Rates and Macro Variables

US



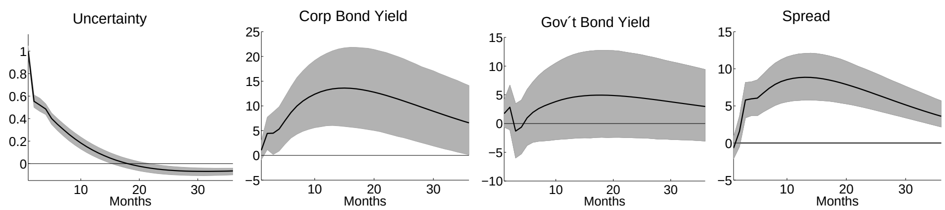
GER



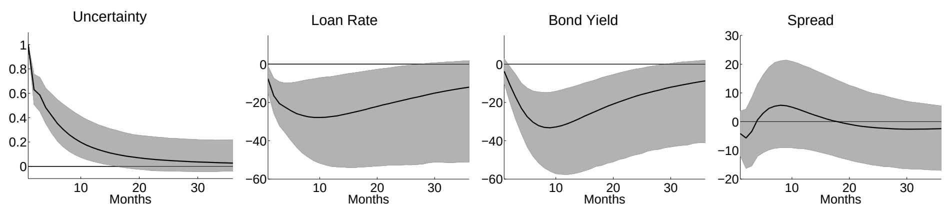
Notes: Effects of a unit shock to the standardized uncertainty series $FDISP^{US}$ and $FDISP^{GER}$, respectively. Uncertainty is expressed in unit values, production and prices are expressed in percent; all other variables in basis points. Monthly VARs are estimated with six variables; both models are estimated with Bayesian techniques. Uncertainty is ordered third after production and prices in a recursive identification. Responses in rows 1 and 2 are estimated with corporate bond yields, those in rows 3 and 4 with bank loan rates. Impulse responses of the spread variables are calculated as the difference between each of the responses of the cost of external finance and the riskless rate. Sample period is from 1997:M4–2017:M6 for the United States and 1996:M11–2017:M6 for Germany. Black solid lines depict the median responses, shaded areas represent 68% error bands.

Figure 7: Robustness V

US: Corporate Bond Yields 1968–2008



GER: Bank Loan Rate 1996–2008



Notes: Effects of a unit shock to the standardized uncertainty series $FDISP^{US}$ and $FDISP^{GER}$, respectively. Uncertainty is expressed in unit values; all other variables are expressed in basis points. Monthly VARs are estimated with three variables. Uncertainty is ordered first in a recursive identification. Impulse responses of the spread variables are calculated as the difference between each of the responses of the cost of external finance and the riskless rate. The VAR for the United States is estimated with the Baa corporate bond yield for the sample period 1968:M5–2008:M8. Black solid lines depict the point estimates, shaded areas represent the 95% confidence intervals based on 5,000 bootstrap replications. The VAR for Germany is estimated with the bank loan rate for the sample period 1996:M11–2008:M8. Due to the short sample, a Bayesian model is estimated. Lag length is set to two. Black solid lines depict the median responses, shaded areas represent 68% error bands.

4 Partial Equilibrium Model of Lending Behavior

The empirical part of this paper shows that uncertainty is accompanied by increases in the cost of bond finance and a reduction in the cost of bank loans. To explain the opposite reactions, this section presents a partial equilibrium model that looks separately at the debt market and the banking sector in times of heightened uncertainty.

The model consists of two periods, $t=1,2$, and two types of lenders – the capital market and a bank – from which firms borrow. All agents are risk and ambiguity neutral. Investment projects are started at the beginning of the period and are terminated at the end of the same period. The investment yields a stochastic payoff $x_t \in [\underline{x}, \bar{x}]$, which is uniformly distributed. This distribution characterizes the low-risk environment.

Firms do not have own resources for their projects and therefore borrow from a lender. They do not individually decide on what type of financing they will pursue, for example, whether to borrow from a bank or the capital market (see, e.g., Holmstrom and Tirole, 1997).

In the model, one set of firms borrows from the capital market and another set receives loans from banks. Apart from this, there is no ex-ante heterogeneity among firms. The reason for not modeling financing choice is that the results in the empirical section suggest that conditional on a small-scale uncertainty shock, the costs of bank and bond finance evolve independently of each other and there is no debt substitution (see Figure 4). Therefore, the opposite movement of loan rates and bond yields cannot be explained by an endogenous switch from one type of debt to another. In contrast, to understand, for example, the large-scale shift from bank to bond finance during the financial crisis of 2008/2009, it is necessary to explicitly model the debt choice (see, e.g., Adrian et al., 2013; Becker and Ivashina, 2014; De Fiore and Uhlig, 2011, 2015).

Following Diamond (1984) and Gale and Hellwig (1985), there is asymmetric information between borrowers and lenders. The distribution from which the payoffs are drawn is known to all agents. The actual draw is the firm's private information; the lender can observe the payoff shock x_t only by taking over the project. Monitoring and liquidating the project involve costs $\bar{\mu}$.

There are two sources of uncertainty in the model: risk and ambiguity (Knightian uncertainty). Risk σ raises the dispersion of the low-risk distribution, from which the payoff shocks are drawn, to $x_t \in [\underline{x} - \sigma, \bar{x} + \sigma]$, which denotes the high-risk distribution. However, changes in risk cannot be perfectly observed by borrowers and lenders as they are accompanied by ambiguity, denoted by parameter a. Firms and lenders become less certain about what the exact distribution of firm returns may be. They have a set of beliefs about the dispersion of this new distribution. In the spirit of Ilut and Schneider (2014), the set of beliefs is parametrized by the interval of dispersions centered around the true dispersion σ:

$$\sigma_a \in [\sigma(1-a), \, \sigma(1+a)] \ . \tag{1}$$

Without acquiring extra information, agents observe the set of dispersions, σ_a, instead of the true size of risk σ.[22] The worst-case dispersion from this belief set is the highest dispersion because, given the lending rate, it implies a higher expected probability of borrower default compared to what the lowest value implies. Both higher risk and higher ambiguity lead to a

[22] The concept of ambiguity as used in this paper deviates from that of Ilut and Schneider (2014). In this paper, ambiguity revolves around the dispersion instead of the mean. Therefore, risk and ambiguity are linked to each other. If risk is positive, $\sigma > 0$, there is ambiguity about the true size of risk. If risk is zero, $\sigma = 0$, there is no ambiguity. In the latter case, agents can assign correct probabilities to all outcomes, and they maximize with respect to the distribution $x_t \in [\underline{x}, \bar{x}]$. As shown later, this formulation of ambiguity does not require that the agents are ambiguity averse.

more dispersed set of beliefs and a higher worst-case dispersion. Agents, who have ambiguous belief sets, choose the worst-case dispersion when evaluating their profits:

$$\sigma_a^* = \max\left[\sigma(1-a),\, \sigma(1+a)\right] \ . \tag{2}$$

They do so because maximizing the lender's profit with respect to the highest possible dispersion results in lower (ex-post) absolute forecast errors compared to the lowest possible dispersion.[23] Therefore, unlike in Ilut and Schneider (2014), the agents do not need to be ambiguity averse.

Risk σ materializes at the beginning of $t=1$ and vanishes at the end of the first period once the lender is repaid or default occurs. Therefore, the first period denotes the short-run period during which uncertainty is elevated. The second period represents the long-run equilibrium in which uncertainty is assumed to be zero, $\sigma_a^* = 0$. However, payoffs are still stochastic in Period 2 and are drawn from the low-risk distribution: $x_2 \in [\underline{x}, \bar{x}]$.

4.1 Capital Market

At the beginning of the first and second periods, one set of firms borrows from the capital market. If the borrower does not default at the end of $t=1$, the capital market receives repayment of the debt, and the contract ends. A firm that defaults is replaced by a new firm, so that a new contract between borrower and lender can take place in Period 2. The capital market relies on publicly available information about the borrower and does not invest in acquiring additional information. Therefore, the structure of the one-period contract does not change from the first to the second period. The one-period problem follows the outline of Williamson (1987) and Walsh (2003).

A firm that borrows from the capital market is able to pay back its debt whenever its revenue, x_t, is larger than its debt, $R_t^C \cdot L_t$, where R_t^C is the cost of bond finance and L_t is the volume of direct credit. Each project requires an investment of one unit; therefore, $L_t = 1$ holds for each period. If the firm announces a revenue $x_t \geq \hat{x}_t$, it repays the loan. $\hat{x}_t$ is the threshold level at which the firm earns just enough from the project to pay its debt R_t^C, which implies that $\hat{x}_t = R_t^C$. After paying its debt, the firm keeps the residual $(x_t - R_t^C)$. The firm defaults if $x_t < \hat{x}_t$; the bond investor monitors the firm, $\bar{\mu}$ is lost in the bankruptcy procedure, and the lender receives $(1-\bar{\mu})\,x_t$. Defaulting firms receive nothing. Taking into account that

[23] The proof for this result is presented in Appendix F.

uncertainty rises at the beginning of the first period, a firm borrows from the capital market in Period 1 only if its expected return is not smaller than zero:

$$E_1 \left\{ \int_{R_1^C}^{\bar{x}+\sigma_a^*} (x - R_1^C)\, dF(x) \right\} \geq 0 \ . \tag{3}$$

The structure of the expected return to firms in the second period is similar, except that $\sigma = 0$ and R_1^C is replaced by R_2^C.

The expected return to the market lender in Period 1 is:

$$E_1 \left\{ \int_{\underline{x}-\sigma_a^*}^{R_1^C} [(1-\bar{\mu})\, x_1]\ dF(x) + \int_{R_1^C}^{\bar{x}+\sigma_a^*} R_1^C\, dF(x) \right\} \ . \tag{4}$$

The first term in Equation (4) is the return to the lender if the borrower defaults; the second term denotes the return if the borrower does not default.

Following Afanasyeva and Güntner (2014), the debt contract is formulated from the lender's perspective, which ensures that bond investors take an active part in determining the cost of market debt. The lender maximizes its expected return (Equation (4)) with respect to the cost of bond finance, R_1^C, subject to the borrower's participation constraint (Equation (3)). The first-order condition is:[24]

$$R_1^C = \frac{1}{1+\bar{\mu}}\ (\bar{x} + \sigma_a^*) \ .$$

An increase in uncertainty σ_a^* raises the cost of market debt R_1^C. Bond investors demand compensation for the increased probability of borrower default. This constitutes the risk compensation channel and is a standard result of a model with CSV. An increase in monitoring costs $\bar{\mu}$ lowers the cost of market finance. This is because firms do not have resources of their own; in case of default, they do not lose their net worth, and the lender bears the costs. A higher $\bar{\mu}$ makes borrower default more costly for the lender, and the lender decreases R_1^C in order to reduce the likelihood of default.

Turning to Period 2, $\sigma = 0$ and the stochastic payoffs are drawn from the low-risk distribution, $x_2 \in [\underline{x}, \bar{x}]$. Bond financing becomes less costly compared to Period 1:

$$R_2^C = \frac{1}{1+\bar{\mu}}\ \bar{x} \ . \tag{5}$$

[24] The complementary slackness condition implies that the borrower's participation constraint (Equation (3)) only binds for $\bar{\mu} = 0$. Since this is a model of asymmetric information, $\bar{\mu} > 0$ holds, and the Lagrange parameter can be dropped. This argument also holds for the second period. The reason the constraint never binds is that firms do not have any resources of their own. Therefore, they cannot lose any net worth when they default and never make negative profits. As there are always some situations in which firms make positive profits, the firms' expected profits have to be larger than zero.

4.2 Banking Sector

Another set of firms borrows from the bank at the beginning of the first and second periods. In contrast to the capital market, the bank builds long-term relationships with its borrowers, which provide the bank with two benefits. First, firms reveal proprietary information to the bank at no cost during Period 1. This information is not publicly distributed because, if it was, the firm's competitors could profit from it (Bhattacharya and Chiesa, 1995). Sharing this knowledge lowers information asymmetries between the firm and the bank in the second period: monitoring costs in Period 1, $\bar{\mu}$, decrease to $(1-k)\,\bar{\mu}$ in Period 2, given that firms survive the first period. The knowledge parameter k governs how much smaller the information asymmetries are between the borrower and the lender in Period 2 compared to Period 1. A higher k implies a greater flow of private information from the firm to the bank. Second, the bank may acquire additional costly market information in Period 1. This information is not known to the firm. More information I about the market in which the firm operates reduces the bank's losses in the event of borrower default. Bankruptcy costs in the second period are lower by the amount $\nu{\cdot}I$, where ν is a parameter that guarantees that the bankruptcy costs in Period 2 remain larger than zero; ν can be interpreted as the value of market information for reducing default costs. Information I is between $[0,1]$; a value of 0 implies no additional market information, a value of 1 stands for the maximum amount of information. Therefore, the costs of bankruptcy of relationship firms in the second period, $\bar{\mu}^B(I)$, become:

$$\bar{\mu}^B(I) = (1-k-\nu\cdot I)\,\bar{\mu}\ .$$

Market information I has another benefit. It reduces the uncertainty of investment projects in the first period by lowering the ambiguous component a.[25] The original set of beliefs, described by expression (1), changes to:

$$\sigma_{a(I)} \in [\sigma\,(1-a\,[1-e\cdot I])\,,\,\sigma\,(1+a\,[1-e\cdot I])]\ ,$$

where e represents how efficient market information is in resolving ambiguity. Note that by acquiring market information, the bank reduces ambiguity a, that is, it lowers the uncertainty surrounding the bounds of the payoff distribution. However, this type of information does not lower risk σ; therefore, the true distribution remains unchanged. As part of the relationship, the bank shares information I with the borrower. All agents take the worst-case dispersion when they evaluate their plans, $\sigma^*_{a(I)} = \max\ \sigma_{a(I)}$. For $I>0$, $\sigma^*_{a(I)}$ is smaller than σ^*_a from

[25] De Fiore and Uhlig (2011) similarly argue that banks can acquire additional information about an economy-wide uncertain productivity factor and adjust the loan contract accordingly, which reduces the riskiness of bank finance for a firm compared to bond finance.

Equation (2), the worst-case dispersion that lenders and borrowers on the capital market expect.

In collecting market information, the bank has to pay two types of costs. First, for a more detailed investigation of the market in which the borrower operates, the bank is required to shift resources within the bank. By doing so, the bank incurs a fixed cost $K_{I>0}$ irrespective of the amount of acquired information. Second, rapidly increasing the amount of information results in higher costs. The bank's adjustment costs are given by $\kappa \frac{1}{1-I}$.

The bank can reap the benefits from private information and some of the gains from information about the business environment only in the second period, and only if the firm does not default in the first period. Therefore, the bank takes into account that its actions in Period 1 have an impact on its return in Period 2. If the borrower does not default in Period 1, the bank rolls over the loan to Period 2 and profits from the informational advantage. If the borrower defaults in the first period, the bank can lend to a different firm in the second period, with the drawback of having no particular information about the new firm. The expected return to the bank is:

$$
\begin{aligned}
E_1 \Bigg\{ & \int_{\underline{x}-\sigma^*_{a(I)}}^{R_1^B} [(1-\bar{\mu})\, x_1]\; dF(x) + \int_{R_1^B}^{\bar{x}+\sigma^*_{a(I)}} R_1^B \; dF(x) \; - \; K_{I>0} \; - \; \kappa \frac{1}{1-I} \\
& + \left(1 - \int_{\underline{x}-\sigma^*_{a(I)}}^{R_1^B} dF(x)\right) \left(\int_{\underline{x}}^{R_2^B} \left[(1-\bar{\mu}^B(I))\, x_2\right] \; dF(x) + \int_{R_2^B}^{\bar{x}} R_2^B \; dF(x) \right) \\
& + \left(\int_{\underline{x}-\sigma^*_{a(I)}}^{R_1^B} dF(x) \right) \left(\int_{\underline{x}}^{\tilde{R}_2^B} [(1-\bar{\mu})\, x_2] \; dF(x) + \int_{\tilde{R}_2^B}^{\bar{x}} \tilde{R}_2^B \; dF(x) \right) \Bigg\} \;, \qquad (6)
\end{aligned}
$$

where R_1^B and R_2^B are the loan rates the relationship firm has to pay the bank in Periods 1 and 2, respectively, and $\tilde{R}_2^B$ is the loan rate paid by a no-relationship firm in Period 2. The first line of Equation (6) describes the expected return in Period 1. The first term represents the expected profit to the bank if the borrower defaults. The lender monitors and liquidates the firm's assets; the amount $\bar{\mu}$ is lost during this procedure. If the borrower does not default, the lender receives the interest rate R_1^B; the expected return for this situation is denoted by the second term. The costs associated with acquiring market information are described by the third and fourth terms.

The second line of Equation (6) accounts for the fact that the decision about the rate R_1^B and information I not only affect the outcome in Period 1, but also in Period 2. An increase in R_1^B increases the probability that the borrower defaults in the first period, ceteris paribus, and reduces the likelihood that the bank can continue the relationship with the borrower in Period 2. This is represented by the first term in parentheses. The second term in parentheses describes the expected return from continuing the relationship. The benefit from the relationship is a drop in the cost of borrower default from $\bar{\mu}$ to $\bar{\mu}^B(I)$.

The third line of Equation (6) describes the situation when the firm defaults in the first period, and the bank lends to a different firm in Period 2 and charges the loan rate $\tilde{R}_2^B$. However, in this case, the bank cannot profit from lower informational asymmetries and the acquired information I is also useless in evaluating the new firm's project.

A firm that forms a relationship with the bank borrows from the bank only when its expected profit is non-negative across the two periods:

$$E_1 \left\{ \int_{R_1^B}^{\bar{x}+\sigma^*_{a(I)}} \left[x_1 - R_1^B\right] \, dF(x) + \left(1 - \int_{\underline{x}-\sigma^*_{a(I)}}^{R_1^B} dF(x)\right) \left(\int_{R_2^B}^{\bar{x}} \left[x_2 - R_2^B\right] \, dF(x)\right) \right\} \geq 0 \ . \quad (7)$$

The first term in Equation (7) is the firm's expected profit in the first period. If a firm does not default in $t=1$, denoted by the expression in the first set of parentheses, it borrows again from the bank to finance a second investment from which it expects a profit, described by the second set of parentheses.

The bank's problem is to choose the lending rates R_1^B, R_2^B, and $\tilde{R}_2^B$ and the amount of information I to maximize Equation (6) subject to the borrower's participation constraints, denoted by Equation (7) and Equation (3) with $R_1^C = \tilde{R}_2^B$ and $\sigma_a^* = 0$. Analytical results can be calculated for the three loan rates; the optimal amount of information I needs to be simulated due to the fixed costs. R_1^B, R_2^B, and $\tilde{R}_2^B$ are:[26]

$$\tilde{R}_2^B = \frac{1}{1+\bar{\mu}} \, \bar{x} \quad (8)$$

$$R_2^B = \frac{1}{1+\bar{\mu}^B(I)} \, \bar{x} \quad (9)$$

$$R_1^B = \frac{1}{1+\bar{\mu}} \left(\bar{x} + \sigma^*_{a(I)}\right) - \frac{1}{2} \frac{1}{\bar{x}-\underline{x}} \frac{\bar{\mu}-\bar{\mu}^B(I)}{1+\bar{\mu}} \left\{ \frac{1}{[1+\bar{\mu}^B(I)](1+\bar{\mu})} \, (\bar{x})^2 - (\underline{x})^2 \right\} \ . \quad (10)$$

If the borrower defaults in Period 1, the bank can lend to a different firm in the second period and demand the loan rate $\tilde{R}_2^B$ (Equation (8)). This rate equals the cost of bond finance in the second period (Equation (5)) because the bank has no private information about this new firm nor any information about the business environment in which this firm operates.

Equation (9) denotes the loan rate paid in Period 2 if the borrower does not default in either period. Compared to the cost of bond finance in Period 2 (Equation (5)) or the loan rate the bank charges a no-relationship-firm (Equation (8)), the bank lending rate is larger by

[26] The complementary slackness condition implies that the first participation constraint (Equation (7)) binds only when $\bar{\mu}=\bar{\mu}^B(I)=0$. The second constraint – Equation (3) where R_1^C is replaced by $\tilde{R}_2^B$ and σ_a^* equals zero – binds only for $\bar{\mu}=0$. Therefore, the Lagrange parameters can be omitted in the subsequent analysis. The reason the constraints do not bind is explained in footnote 24.

the amount $k \cdot \bar{\mu} + \nu \cdot I \cdot \bar{\mu}$. This represents the markup the bank can charge when it establishes a relationship with the borrower. The loan markup can increase for three reasons. First, the bank receives more proprietary information from the firm (an increase in k). Second, the bank acquires additional information about the firm's business environment (a higher I). Third, the bank may learn more from a marginal unit of this information (a rise in ν). All three factors enable the lender to charge higher loan rates because the default situation is less feared by the lender since it is now less costly. These costs are borne by the lender because firms do not lose their net worth when they default. Therefore, the costs of bank finance are higher compared to bond finance in the second period, which denotes the long run. This is consistent with real-world data. On average, bank loan rates are higher than corporate bond yields.[27] In this way, banks can accommodate their borrowers in economically bad times (described by the first period) with more favorable loan conditions in an effort to maintain their customer relationships.

Equation (10) describes the bank loan rate in Period 1. There are two channels through which the loan rate may change as uncertainty increases, and they work in opposite directions. First, given information $I = \bar{I}$, an increase in risk raises the cost of bank finance:

$$\left.\frac{\partial R_1^B}{\partial \sigma}\right|_{I=\bar{I}} = \frac{1}{1+\bar{\mu}} \left[1 + a(1 - e \cdot \bar{I})\right] > 0 \ .$$

Risk increases the probability of borrower default, and the bank demands compensation in the form of a higher loan rate. This is the risk compensation channel that bond investors also face (when $e = 0$). Second, banks may acquire more information I in times of elevated uncertainty. Taking the derivative of Equation (10) with respect to I gives:

$$\frac{\partial R_1^B}{\partial I} = -\left\{ \frac{1}{1+\bar{\mu}} \sigma \cdot a \cdot e + \frac{1}{2} \frac{1}{\bar{x} - \underline{x}} \frac{\nu \cdot \bar{\mu}}{1+\bar{\mu}} \left[\frac{1}{\left[1+\bar{\mu}^B(I)\right]^2} (\bar{x})^2 - (\underline{x})^2 \right] \right\} < 0 \ .$$

Acquiring additional market information leads to a reduction in the loan rate for two reasons. First, it reduces ambiguity. The set of beliefs that the agents hold becomes less dispersed, which lowers the worst-case dispersion. This reduces the probability of borrower default, thereby decreasing the lending rate. Second, having collected more information in the first period, bankruptcy costs are lower in the second period, making it more attractive for the bank to continue the relationship with the borrower in Period 2. By reducing the lending rate in Period 1, borrower default in the first period becomes less likely and the bank profits from lower bankruptcy costs in Period 2. These two effects constitute the information channel.

[27] For example, for the United States the rate on loans with a maturity of one year is 4.2% for the time period 1997:Q2 to 2017:Q2, while the yield on corporate bonds with a maturity of one to three years is 3.8%.

When the information channel dominates the risk compensation channel, the loan rate falls during periods of heightened uncertainty.

4.3 Simulation of the Banking Sector

The model is now simulated to discover under what conditions banks endogenously acquire more information, and whether this results in the information channel dominating the risk compensation channel.

4.3.1 Calibration

Table 1 summarizes the parameter values. The monitoring costs $\bar{\mu}$ are set to 0.20, a value often used in the literature. The interval bounds $\bar{x}$ and $\underline{x}$, and the knowledge parameter k, are chosen to obtain reasonable values for the default rate, and the loan rates R_2^B and $\tilde{R}_2^B$ when there is no risk, $\sigma = 0$, and no acquisition of market information, $I = 0$, for the United States. Specifically, I match an annualized default rate of 3.0%, a bank loan rate of 4.2%, and a corporate bond yield of 3.8% due to $\tilde{R}_2^B = R_2^C$. Acquiring private information, $k = 0.023$, results in a markup of 40 basis points on the bank loan rate compared to the corporate bond yield. Given the maximum possible amount of market information, $I = 1$, ν is calibrated so that the lower bound for $\bar{\mu}^B(I)$ is 0.15, a value often found in the literature.

The ambiguity parameter a is set to 1 so that an increase in risk σ raises total uncertainty $\sigma^*_{a(I=0)}$ twice as much. This reflects the finding of Rossi et al. (2016) that both ambiguity and risk are important components of total uncertainty. There are two scenarios for risk σ. In the low-risk scenario, σ is set to 0. In the high-risk scenario, σ is calibrated to match the average rise in the corporate bond yield found in the VAR exercises of roughly 15 basis points on impact, which implies $R_1^C = 3.95\%$.

There are three parameters that are not straightforward to calibrate. The fixed costs $K_{I>0}$ and the adjustment costs κ of market information acquisition are assumed to equal a fraction θ_{fix} and θ_{adj} of the standard deviation of the distribution of payoffs x, respectively. θ_{fix} varies between 0% and 15% and θ_{adj} lies between 0% and 2.5%. De Fiore and Uhlig (2011) estimate that the fixed costs of information acquisition are equal to 0.1% of the accumulated capital stock. In this paper, the maximum possible information costs equal 17.5% of the standard deviation of investment returns from a single project. Finally, the parameter e, which governs how much market information can reduce ambiguity, can take on values between [0,1]. $e = 1$ implies that one unit of information reduces ambiguity to zero.

Table 1: Parameter Values

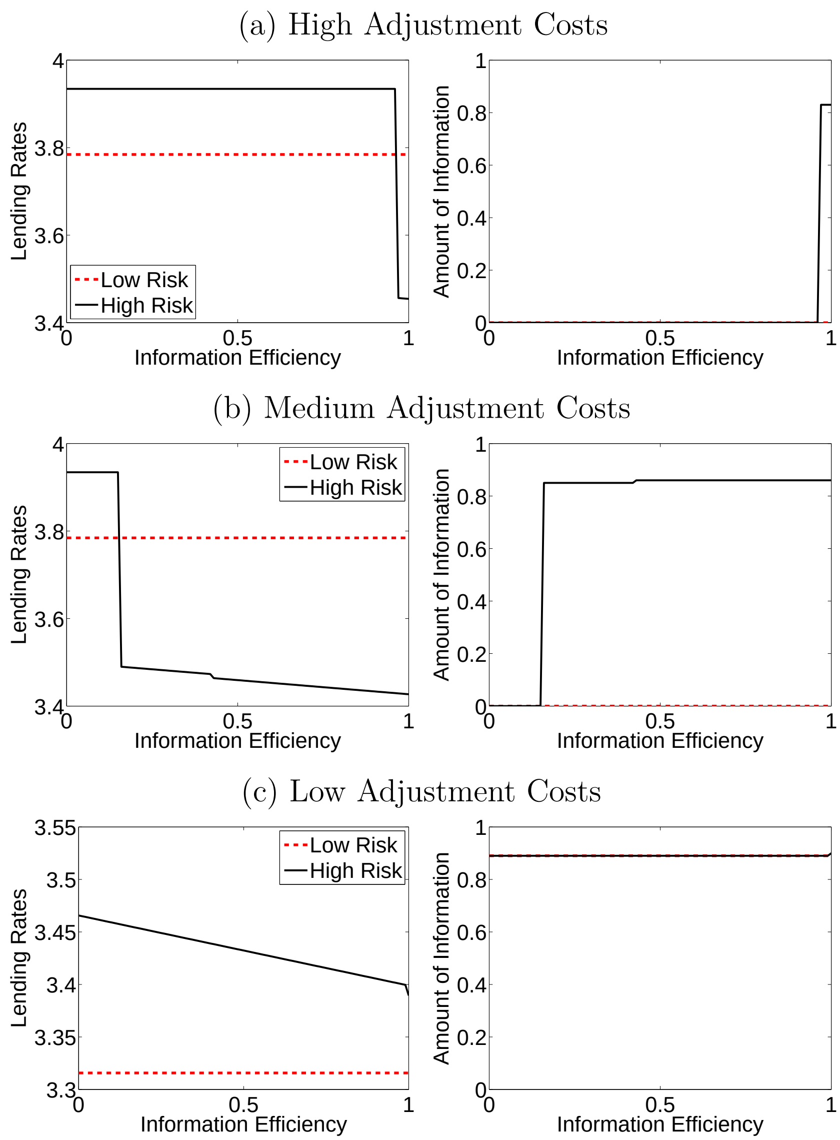
Parameter	Value	Description
$\bar{x}$	1.2456	Upper Bound of Interval
$\underline{x}$	1.0316	Lower Bound of Interval
$\bar{\mu}$	0.20	Monitoring Cost
k	0.023	Markup Due to Private Knowledge Transfer
ν	0.227	Markup Due to Market Information
a	1	Ambiguity
σ	0 or 0.0009	Low Risk or High Risk
e	[0,1]	Efficiency of Market Information
θ_{fix}	[0,0.15]	Fixed Cost of Information Acquisition
θ_{adj}	[0,0.025]	Adjustment Cost of Information Acquisition

4.3.2 Results

Figure 8 plots the loan rate in the first period (left panel) and the acquisition of market information (right panel) as the information efficiency parameter e increases from 0 to 1 for a given value of the fixed cost parameter. Low and high risk are represented by dashed and solid lines, respectively. Panel (a) is computed using a relatively high adjustment cost parameter. Only when information is very valuable in reducing ambiguity, implying a high e, does the information channel dominate the risk compensation channel. Then, a bank acquires additional information in the high-risk state and reduces the lending rate below the rate in the low-risk state. A high information efficiency implies that a small amount of additional information is sufficient to substantially reduce ambiguity, and the high adjustment costs do not become too large. At lower levels of e, the gain from acquiring more information is not large enough to offset the cost. No additional information is acquired in the high-risk state; ambiguity remains elevated, for which the lender wants to be compensated. Here, risk compensation is more important for the bank than acquiring market information, and the lending rate in the high-risk state is larger relative to the low-risk rate.

For medium-sized adjustment costs, the lender collects further information in the high-risk state even at lower degrees of information efficiency. Therefore, the range in which the lending rate in the high-risk state is lower than in the low-risk state is larger (Panel (b) of Figure 8). Panel (c) shows that low information adjustment costs induce the bank to acquire market information in the low-risk state too, so as to profit from lower bankruptcy costs in the future. Therefore, the bank offers a lending rate in the low-risk state that is always below the high-risk rate, regardless of the size of the information efficiency parameter. In this situation, an uncertainty increase is not the trigger for acquiring information, as a sufficient amount of information is already acquired in the low-risk state due to the low adjustment cost.

Figure 8: Simulation Results I

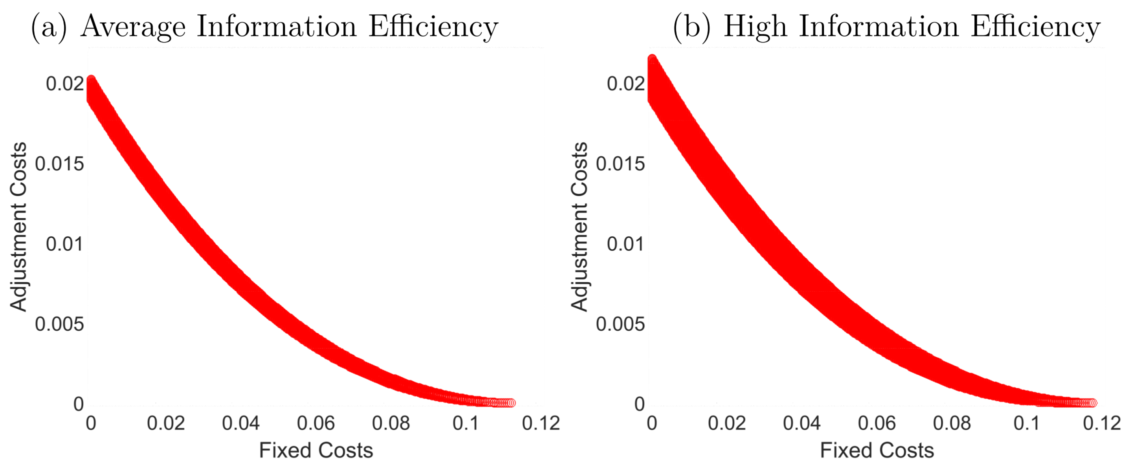


Notes: Each row plots the evolution of the lending rate in the first period and the amount of market information for different values of the information efficiency parameter, $e = [0, 1]$, and different adjustment costs of information acquisition, $\theta_{adj} = (0.005, 0.0035, 0.002)$, in Panels (a), (b), and (c), respectively. θ_{fix} is equal to 0.06. Dashed lines denote values that are simulated when risk is low ($\sigma = 0$), solid lines when risk is high ($\sigma = 0.0009$).

The previous analysis emphasized the role of information efficiency for certain information cost parameters. To arrive at a complete picture of when bank loan rates fall after uncertainty increases, Figure 9 shows in (θ_{fix}, θ_{adj}) space the ranges in which the high-risk rate is higher or lower compared to the low-risk rate. Panel (a) is computed using an average value of information efficiency ($e = 0.5$), Panel (b) relies on a high value ($e = 0.9$). The area in red depicts all combinations of the two cost parameters that lead to a reduction in the lending rate in the first period as the economy moves from a low- to a high-risk state. All values outside this red area represent combinations that yield a loan rate increase. For both efficiency values, the red area is downward-sloping. When a bank faces relatively high fixed costs of information acquisition, it will be profitable to collect information and reduce loan rates only when information adjustment costs are low. At lower fixed costs, adjustment costs should not be either too large or too small; otherwise, lending rates will increase. If adjustment costs are too high, increasing the amount of information will become too costly and the bank raises the lending rate instead. If these costs are too small, banks also acquire additional information in the low-risk state to benefit from lower future bankruptcy costs, so that the loan rate charged remains lower than the high-risk rate. Comparing Panels (a) and (b) shows that higher information efficiency implies a widening of the area in which high-risk rates are less than low-risk rates.

As a final note, if there are no adjustment costs, $\theta_{adj} = 0$, the fixed costs need to be somewhere between 10% and 12% of the standard deviation of the distribution of payoffs x (for average or high levels of information efficiency), so that bank loan rates fall in times of heightened uncertainty. If the fixed costs are below or above that range, banks act like capital market debt holders and raise lending rates in response to uncertainty shocks.

Figure 9: Simulation Results II



Notes: Denoted in red is the area in which the bank lending rate in the first period falls as the economy moves from low risk ($\sigma = 0$) to high risk ($\sigma = 0.0009$) for different fixed and adjustment costs of information acquisition, $\theta_{fix} = [0, 0.15]$ and $\theta_{adj} = [0, 0.025]$. The left panel shows results for average information efficiency ($e = 0.5$), the right panel for high information efficiency ($e = 0.9$).

5 Conclusion

Based on the results in this paper, two suggestions can be made for economic policy and future research. First, the results provide support for stronger bank capital requirements. The paper shows that after an uncertainty shock, banks continue to lend to borrowers for several months. Banks are accommodating toward their borrowers in the sense that they reduce loan rates and keep spreads constant. This means that they take on more risk by agreeing to make loans to borrowers with a more uncertain outlook without being adequately compensated in the short term. Taking on more risk for an extended period of time, however, is possible only for well-capitalized banks. Banks that are better capitalized may continue to lend to firms in periods of heightened uncertainty at lower rates so as to maintain their borrower relationships. Weakly capitalized banks cannot maintain these relationships for long and, subsequently, need to reduce their lending and cannot mitigate the adverse consequences of uncertainty for their clients. Thus, higher capital requirements may reduce the number of banks unable to maintain relationship lending during an uncertainty episode.

Second, DSGE models with financial frictions generate increases in spreads as uncertainty increases, thereby producing real negative effects for output. The results in this paper show that only corporate bond spreads increase as uncertainty rises; bank loan spreads do not react. Therefore, future DSGE models that look at the uncertainty-financial-friction link while explicitly modeling bank behavior need to take into account that bank spreads do not increase in response to uncertainty shocks. The adverse effects instead stem from a slow reduction in lending activity of weakly capitalized banks.

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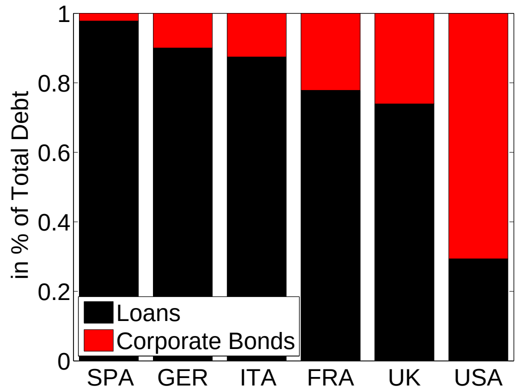
Appendix

A Debt Financing Across Different Countries

Figure 10: Debt Financing of Nonfinancial Corporations in 2015



Notes: Data for Spain, Germany, Italy, France, and the United Kingdom are from the financial balance sheets of Eurostat's quarterly sector accounts. For the United States, the data are from the financial accounts statistic of the Federal Reserve Board. Loans and corporate bonds as shares of total debt are calculated for 2015.

B Construction of the Business Uncertainty Proxies

For Germany, I use manufacturing firms' responses to the monthly ifo Business Climate Survey (ifo-BSC). The Business Climate Index, which is based on this survey, is a much-followed leading indicator for economic activity in Germany. I focus on the following question from the survey:

> Expectations for the next three months: Our domestic production activities with respect to product X will (without taking into account differences in the length of months or seasonal fluctuations) increase, roughly stay the same, decrease.

Exp_t^+ is defined as the fraction of firms that expect at time t an increase in production activity and Exp_t^- as the fraction of firms that expect a decrease. Uncertainty is proxied by the cross-sectional dispersion of expectations about future production:

$$FDISP_t^{GER} = \sqrt{Exp_t^+ + Exp_t^- - (Exp_t^+ - Exp_t^-)^2} \ . \quad (11)$$

For the United States, I use data from the Business Outlook Survey (BOS), which is conducted on a monthly basis by the Federal Reserve Bank of Philadelphia and surveys large manufacturing firms in the Third Fed District.[28] I focus on the following question from the survey:

> General Business Conditions: What is your evaluation of the level of general business activity six months from now vs. [Current Month]: decrease, no change, increase?

In contrast to what is available for the IFO-BSC, I do not have access to detailed micro data from the BOS. However, the net balances Exp_t^+ and Exp_t^- are available. Using Equation (11), I calculate the uncertainty proxy for the United States, $FDISP^{US}$, as the dispersion of firms' forecasts about the general business outlook.

[28] Bachmann et al. (2013) argue that the BOS is representative of the entire United States. They find that economic activity as measured in the BOS is highly correlated with (national) manufacturing industrial production.

C Data

Table 2: Data Sources: United States

Variable	Description	Source
$FDISP^{US}$	Cross-sectional standard deviation of business expectations, manufacturing firms, Third FED District, seasonally adjusted with X-12 and standardized	BOS & own calculations
Corporate bond yield 1–3y	Effective yield of investment-grade-rated corporate debt with maturity between 1 and 3 years	Merrill Lynch
Corporate bond yield 30y	Effective yield of Baa-rated corporate debt with maturity of 30 years	Moody's
Corp bond volume	Corporate bonds, new security issues, non-financial corporations, 12-month cumulative values and standardized	Federal Reserve Board
Loan rate 1y	Charged by commercial banks for all new commercial and industrial loans, up to 1 year, interpolated from quarterly to monthly frequency*, in % p.a.	Federal Reserve Board
Loan rate 1y/min	Charged by commercial banks for all new commercial and industrial loans, up to 1 year, with minimal risk, interpolated from quarterly to monthly frequency*, in % p.a.	Federal Reserve Board
Loan rate 1y/low	Charged by commercial banks for all new commercial and industrial loans, up to 1 year, with low risk, interpolated from quarterly to monthly frequency*, in % p.a.	Federal Reserve Board
Loan rate 1y/mod	Charged by commercial banks for all new commercial and industrial loans, up to 1 year, with moderate risk, interpolated from quarterly to monthly frequency*, in % p.a.	Federal Reserve Board
Loan rate 1y/acc	Charged by commercial banks for all new commercial and industrial loans, up to 1 year, with other risk (acceptable), interpolated from quarterly to monthly frequency*, in % p.a.	Federal Reserve Board
Loan rate uncommitted	Charged by commercial banks for all new commercial and industrial loans, loans not under commitment, interpolated from quarterly to monthly frequency*, in % p.a.	Federal Reserve Board
Loan volume 1y	Newly issued commercial and industrial loans, up to 1 year, linearly interpolated from quarterly to monthly frequency, standardized	Federal Reserve Board

Continued on next page

Table 2: Data Sources: United States (cont.)

Variable	Description	Source
Loan volume 1y/min	Newly issued commercial and industrial loans, up to 1 year, with minimal risk, linearly interpolated from quarterly to monthly frequency, standardized	Federal Reserve Board
Loan volume 1y/low	Newly issued commercial and industrial loans, up to 1 year, with low risk, linearly interpolated from quarterly to monthly frequency, standardized	Federal Reserve Board
Loan volume 1y/mod	Newly issued commercial and industrial loans, up to 1 year, with moderate risk, linearly interpolated from quarterly to monthly frequency, standardized	Federal Reserve Board
Loan volume 1y/acc	Newly issued commercial and industrial loans, up to 1 year, with other risk (acceptable), linearly interpolated from quarterly to monthly frequency, standardized	Federal Reserve Board
Prime rate	Charged by commercial banks, used to price short-term business loans, in % p.a.	Federal Reserve Board
Government bond yield 1y	1-year treasury bond yield, in % p.a.	Federal Reserve Board
Government bond yield 3y	3-year treasury bond yield, in % p.a.	Federal Reserve Board
Government bond yield 3m	3-month treasury bond yield, in % p.a.	Federal Reserve Board
Federal Funds Rate	Fed Funds Effective Rate, in % p.a.	Federal Reserve Board
Shadow Rate	Interest rate consistent with the term structure of interest rates for the United States	Wu and Xia (2016)
Lending standards	Average of net percentage of domestic banks increasing collateral requirements, tightening loan covenants, and reducing the maximum maturity, average of large, middle, and small-sized firms, standardized	Senior Loan Officer Opinion Survey
Production	Manufacturing sector, seasonally adjusted, constant prices	Federal Reserve Board
Prices	Consumer Price Index, All Urban Consumers, U.S. City Average, seasonally adjusted	Bureau of Labor Statistics

* The series is interpolated with the Chow-Lin procedure using the prime rate as the monthly interpolator variable.

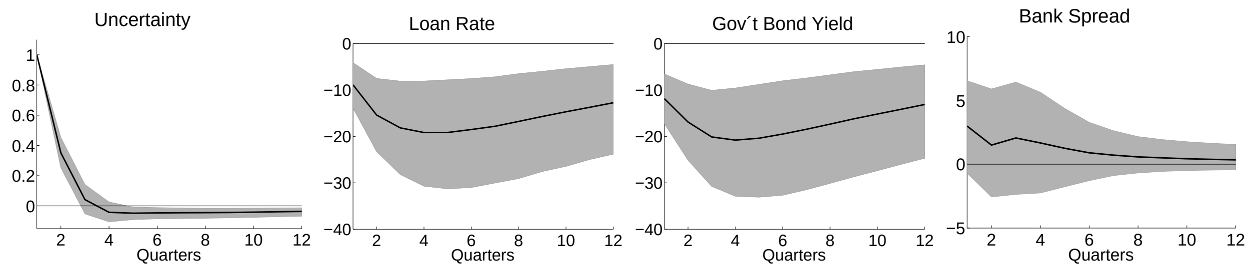
Table 3: Data Sources: Germany

Variable	Description	Source
$FDISP^{GER}$	Cross-sectional standard deviation of production expectations, manufacturing firms, seasonally adjusted with X-12 and standardized	ifo & own calculations
Corp bond yield	Yields on fully taxed bonds outstanding, issued by non-financial corporations, average maturity of 6 years	Bundesbank
Corp bond volume	Securities other than shares, excluding financial derivatives, net issues (flows), non-financial corporations, 12-month cumulative values and standardized	ECB Statistical Data Warehouse
Loan rate	Loan rate for loans other than revolving loans and overdrafts, non-financial corporations, newly issued, up to 1 year, in % p.a.	Bundesbank
Loan rate before 2003	Medium- and long-term loans to enterprises, in % p.a.	Bundesbank
Loan volume	Loans other than revolving loans and overdrafts, non-financial corporations, newly issued, up to 1 year, standardized	Bundesbank
Loan volume before 2003	Lending to non-MFIs, standardized	Bundesbank
Government bond yield 1y	1 to 2 years of maturity, in % p.a.	Bundesbank
Government bond yield 6y	5 to 6 years of maturity, in % p.a.	Bundesbank
EONIA	Day-to-day money market rate, monthly average, in % p.a.	Bundesbank
Shadow Rate	Interest rate consistent with the term structure of interest rates for the Euro Area	Wu and Xia (2017)
Production	Manufacturing sector, seasonally adjusted, constant prices	Federal Statistical Office
Prices	Consumer Price Index, calendar and seasonally adjusted	Bundesbank

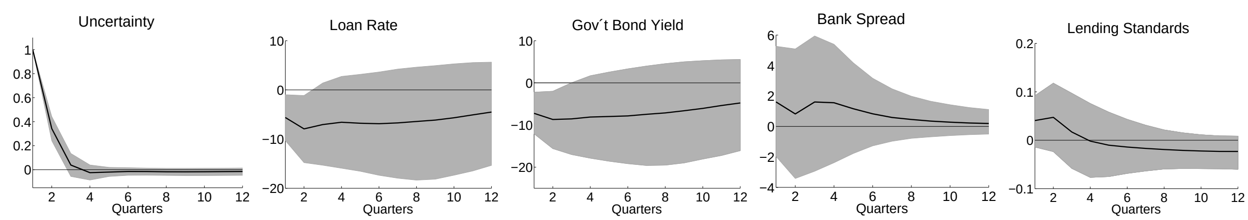
D Additional VAR Results

Figure 11: USA: Models Estimated at Quarterly Frequency

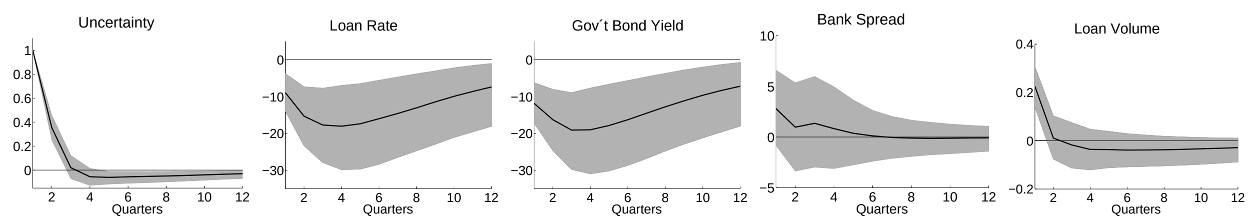
(a) Baseline Variables



(b) Baseline Variables + Lending Standards

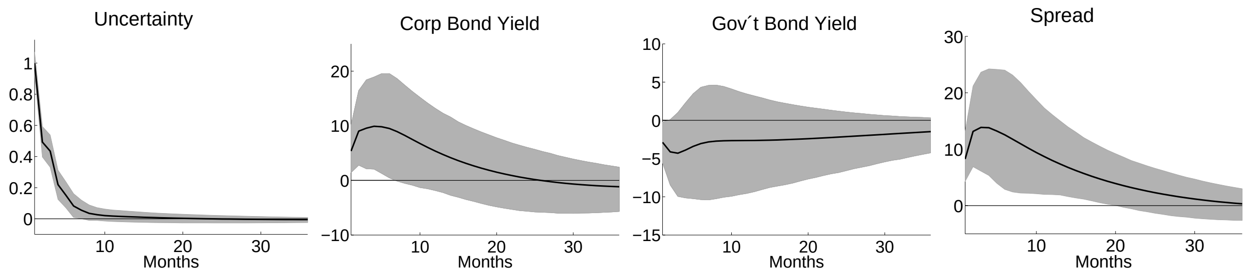


(c) Baseline Variables + Loan Volumes



Notes: Effects of a unit shock to the standardized uncertainty series $FDISP^{US}$. Uncertainty is expressed in unit values, lending standards and loan volumes in standard deviations; all other variables are expressed in basis points. Quarterly Bayesian VARs are estimated with three variables (Panel (a)), and four variables (Panels (b) and (c)). Compared to the monthly baseline VAR, the quarterly model has a relative small number of observations, so that a Bayesian model is estimated. Lag length is set to two. Uncertainty is ordered first in a recursive identification. Impulse response of the spread variable is calculated as the difference between each of the responses of the loan rate and the government bond yield. Sample period is from 1997:q2–2017:q2. Black solid lines depict the median responses, shaded areas represent 68% error bands.

Figure 12: USA: Baseline VAR Estimated with Three-Year Government Bond Yield



Notes: Effects of a unit shock to the standardized uncertainty series $FDISP^{US}$. Uncertainty is expressed in unit values; all other variables are expressed in basis points. Compared to the baseline model, the VAR includes a three-year government bond yield instead of a one-year bond yield. Monthly VARs are estimated with three variables. Uncertainty is ordered first in a recursive identification. Impulse response of the spread variable is calculated as the difference between each of the responses of the corporate and the government bond yield. Sample period is from 1997:M4–2017:M6. Black solid lines depict the point estimates, shaded areas represent the 95% confidence intervals based on 5,000 bootstrap replications.

E Adverse Selection, Moral Hazard, and Risk

This section investigates whether a lower lending rate during periods of elevated risk could be due to adverse selection or moral hazard. Banks may be reluctant to raise interest rates when risk increases because this may shift the composition of their loan portfolio toward borrowers with riskier projects (adverse selection) or because they fear that borrowers will switch to riskier projects (moral hazard).

E.1 Adverse Selection

This section shows that the presence of adverse selection implies higher lending rates when risk increases. The structure of the model is based on the Walsh (2003) version of the Stiglitz and Weiss (1981) model. Firms invest in projects that yield a return of $R+x^{\sigma}$ with probability $\frac{1}{2}$ and $R-x^{\sigma}$ with probability $\frac{1}{2}$. x^{σ} equals $x+\sigma$, where x denotes the normal riskiness of the project and σ is additional risk; the latter can be thought of as a risk shock that is observable by all agents. Projects are fully financed by bank loans L, on which the interest rate R^B is paid. Each project requires an investment of one unit; therefore, $L=1$. If the project yields the high return, $R+x^{\sigma}$, the loan is repaid and the firm receives $R+x^{\sigma}-R^B$. If the project yields the low return, $R-x^{\sigma}$, the borrower defaults and receives nothing; the bank receives the project return. The expected profit to a firm is:

$$E\pi^{Firm} = \frac{1}{2}\left[R+x^{\sigma}-R^{B}\right] \ ,$$

from which the threshold level $\hat{x}^\sigma$ can be derived at which $E\pi^{Firm}$ equals zero,

$$\hat{x}^\sigma = R^B - R \ .$$

The threshold increases in R^B. There are two types of borrowers, one with low-risk projects, $x^\sigma = x_l^\sigma$, and one with higher-risk investments, $x^\sigma = x_h^\sigma > x_l^\sigma$. Both types are equally likely. If the loan rate is low enough so that $\hat{x}^\sigma \leq x_l^\sigma < x_h^\sigma$, both groups of firms borrow from the bank. The bank return is:

$$E\pi^{Bank} = \frac{1}{2}\left[R^B + R\right] - \frac{1}{4}(x_l^\sigma + x_h^\sigma) \ .$$

The bank return increases with R^B as long as the threshold level $\hat{x}^\sigma$ is smaller than x_l^σ. However, if the bank raises R^B by enough that the threshold level is above x_l^σ, all low-risk type borrowers stop borrowing. Therefore, if $x_l^\sigma \leq \hat{x}^\sigma \leq x_h^\sigma$, the bank return drops to:

$$E\pi^{Bank} = \frac{1}{2}\left[R^B + R\right] - \frac{1}{2}x_h^\sigma \ .$$

The bank profit falls when the lending rate is:

$$R_\sigma^B = x_l^\sigma + R \ , \tag{12}$$

because of the shift in the composition of the bank's loan portfolio toward borrowers with high-risk projects. Evaluating Equation (12) at $x_l^{\sigma=0}$ (when there is no additional risk) and, again, at $x_l^{\sigma>0}$ (when there is additional risk), gives:

$$R_{\sigma=0}^B < R_{\sigma>0}^B \ .$$

If the lender cannot observe the borrower's risk type, it is optimal to increase the lending rate when there is additional risk because higher risk implies that borrowers gain on the upside, while having limited liability on the downside. Both x_l^σ and x_h^σ increase. A higher x_l^σ implies that the threshold value $\hat{x}^\sigma$ can also increase without a drop out of all borrowers with relatively low-risk projects. A higher $\hat{x}^\sigma$ is associated with a higher lending rate.

E.2 Moral Hazard

This section shows that moral hazard implies higher loan rates when risk increases. The structure of the model is based on the Walsh (2003) version of the Stiglitz and Weiss (1981) model. A firm can either invest in project l, which yields a return of $R + x_l^\sigma$ with probability p_l and $R - x_l^\sigma$ with probability $1 - p_l$, or it invests in project h with a yield of $R + x_h^\sigma$ with probability p_h and $R - x_h^\sigma$ with probability $1 - p_h$. x_i^σ equals $x_i + \sigma$, where $i = (l, h)$ is the type of project risk, x_i denotes the normal riskiness of project i, and σ is additional risk; the latter can be thought of as a risk shock that is observable by all agents. Project h is riskier than l with $x_h^\sigma > x_l^\sigma$ and $p_l > p_h$. Projects are fully financed by bank loans L, on which the interest rate R^B is paid. Each project requires an investment of one unit; therefore, $L = 1$. If either of the two projects yields a high return, $R + x_i^\sigma$, the loan is repaid and the firm receives $R + x_i^\sigma - R^B$. If project i yields a low return, $R - x_i^\sigma$, the borrower defaults and receives nothing; the bank receives the project return. Investing in project l, the firm can expect a profit of:

$$E\pi_l^{Firm} = p_l \left[R + x_l^\sigma - R_B\right] \ ,$$

while the expected return from project h is:

$$E\pi_h^{Firm} = p_h \left[R + x_h^\sigma - R_B\right] \ .$$

If the expected profits of the two projects are equal, $E\pi_l^{Firm} = E\pi_h^{Firm}$, the threshold value for the loan rate, $\hat{R}^B$, at which the firm is indecisive between the two projects, can be derived:

$$\hat{R}^B = \frac{p_l(R + x_l^\sigma) - p_h(R + x_h^\sigma)}{p_l - p_h} \ . \tag{13}$$

If the loan rate is below $\hat{R}^B$, the firm prefers the project with lower risk l, and the expected return to the bank is:

$$E\pi_l^{Bank} = p_l \cdot R^B + (1 - p_l)(R - x_l^\sigma) \ .$$

If, instead, $R^B > \hat{R}^B$, the firm invests in the riskier project h. The bank's expected profit drops to:

$$E\pi_h^{Bank} = p_h \cdot R^B + (1 - p_h)(R - x_h^\sigma) \ ,$$

because $E\pi_l^{Bank}(\hat{R}^B) > E\pi_h^{Bank}(\hat{R}^B)$.[29] Therefore, the bank has an incentive not to raise the loan rate above $\hat{R}^B$ given a level of risk σ. Evaluating Equation (13) at $x_l^{\sigma=0}$ (when there is no additional risk) and, again, at $x_l^{\sigma>0}$ (when there is additional risk) yields:

$$\hat{R}^B_{\sigma=0} < \hat{R}^B_{\sigma>0} \ ,$$

because $p_l > p_h$. If the bank cannot observe which of the projects the borrower chooses, it is still optimal to raise the loan rate when risk increases because all projects become riskier, and the borrower switches to the riskier project h only at a higher lending rate.

[29] This is because $x_h^\sigma(1 - 2p_h) - x_l^\sigma(1 - 2p_l) > 0$.

F Ex-Post Forecast Errors and Ambiguity

This section shows that the (ex-post) absolute forecast errors derived from the lowest possible dispersion, $\sigma(1-a)$, are higher than from the highest possible dispersion, $\sigma(1+a)$.

The forecast error, FE, equals $\pi - E[\pi]$, where π is the lender's realized profit and $E[\pi]$ is the expected profit. The realized profit depends on the true level of risk, σ, while the expected profit depends on $\sigma_a \in [\sigma(1-a), \sigma(1+a)]$. To compute the forecast error for the highest possible dispersion, FE_h, I use $\sigma_{a,h} = \sigma(1+a)$ and the associated loan rate, $R_h = \bar{x} - \bar{\mu} + \sigma_{a,h}$, which yields:

$$\begin{aligned} FE_h = & [\alpha_1 - \alpha_2]\left[\delta_1 - \frac{1}{2}\frac{1}{1+\mu}\sigma^2(1+a)^2\right] - \left[\alpha_1 - \alpha_2(1+a)^2\right]\delta_2 \\ & + [\alpha_1 - \alpha_2(1+a)]\left[\delta_3 + \frac{1}{1+\mu}\sigma^2(1+a)\right] \end{aligned}$$

where

$$\begin{aligned} \alpha_1 &= \frac{1}{\bar{x} - \underline{x} + 2\sigma} \\ \alpha_2 &= \frac{1}{\bar{x} - \underline{x} + 2\sigma + 2\sigma a} \\ \delta_1 &= \frac{1}{2}\frac{1}{1+\mu}(\bar{x})^2 \\ \delta_2 &= \frac{1}{2}(1-\mu)\sigma^2 \\ \delta_3 &= (1-\mu)\underline{x}\sigma + \frac{1}{1+\mu}\bar{x}\sigma \ . \end{aligned}$$

The forecast error for the lowest possible dispersion, FE_l, depends on $\sigma_{a,l} = \sigma(1-a)$ and the associated loan rate, $R_l = \bar{x} - \bar{\mu} + \sigma_{a,l}$, which yields:

$$\begin{aligned} FE_l = & [\alpha_1 - \alpha_3]\left[\delta_1 - \frac{1}{2}\frac{1}{1+\mu}\sigma^2(1-a)^2\right] - \left[\alpha_1 - \alpha_3(1-a)^2\right]\delta_2 \\ & + [\alpha_1 - \alpha_3(1-a)]\left[\delta_3 + \frac{1}{1+\mu}\sigma^2(1-a)\right] \end{aligned}$$

where

$$\alpha_3 = \frac{1}{\bar{x} - \underline{x} + 2\sigma - 2\sigma a} \ .$$

Taking the absolute values of the forecast errors, $\text{abs}(FE_l) = |FE_l|$ and $\text{abs}(FE_h) = |FE_h|$, I find that

$$\begin{aligned} &\underbrace{\left|\beta_1 - \alpha_3\delta_1 + (1-a)^2\left[\beta_2 + \alpha_3\beta_3\right] + (1-a)\left[\beta_2 - \alpha_3\delta_3\right]\right|}_{\text{abs}(FE_l)} \\ &> \underbrace{\left|\beta_1 - \alpha_2\delta_1 + (1+a)^2\left[\beta_2 + \alpha_2\beta_3\right] + (1+a)\left[\beta_2 - \alpha_2\delta_3\right]\right|}_{\text{abs}(FE_h)} \end{aligned}$$

where

$$\begin{aligned} \beta_1 &= \delta_1 - \delta_2 + \delta_3 \\ \beta_2 &= -\frac{1}{2}\frac{1}{1+\mu}\alpha_1\sigma^2 \\ \beta_3 &= -\frac{1}{2}\frac{1}{1+\mu}\sigma^2 + \delta_2 \ . \end{aligned}$$

The inequality $\text{abs}(FE_l) > \text{abs}(FE_h)$ holds because $\alpha_3 > \alpha_2$.