

Bank Interconnectedness and Monetary Policy Transmission: Evidence from the Euro Area

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**Sofia Álvarez, Michael Barczay, Guadalupe Galambos,
Ina Sandler, Rasmus Schmidt**

Supervisors: Fernando Broner and Antonio Ciccone

Abstract

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Whereas monetary policy is conducted by the European Central Bank, the real effects of these decisions provoke different reactions among euro area countries. One common explanation for this finding is structural heterogeneity across the members of the euro area. We assess how commercial bank interconnectedness – as a specific source of structural heterogeneity – affects the propagation of common monetary policy shocks across the different countries of the euro area between 2003 and 2018. While recent research has found that bank interconnectedness plays an important role in the transmission of monetary policy in the US, evidence on the euro area is scarce. Recent research has shown that bank interconnectedness – in the form of inter-bank lending – can counteract the contraction in loans resulting from a monetary policy tightening. We test this hypothesis empirically by constructing a panel data set for the original euro area countries, creating a measure for country-specific bank interconnectedness, and identifying an exogenous monetary policy shock based on high-frequency data. Using local projections, we provide evidence that – in accordance with the theoretical model we discuss – a contractionary monetary policy surprise leads to a reduction in the supply of corporate and household loans in countries with a low degree of interconnectedness. Conversely, when the banking sector is highly interconnected, the impact of monetary policy is reduced or even counteracted. This implies that a common monetary policy shock can have heterogeneous effects among countries of the euro area, depending on the degree of interconnectedness of their banking industry. Our results are robust to the inclusion of a wide set of controls and alternative shock specifications.

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1 Introduction

“Heterogeneity is part of the euro area’s DNA.”

Benoît Cœuré

In that way, Benoît Cœuré, member of the Executive Board of the European Central Bank (ECB), concluded his speech on heterogeneity and the ECB’s monetary policy at the Banque de France in March 2019. Heterogeneity within the euro area takes many different forms. Member countries differ in the type and frequency of the shocks they experience, which is usually referred to as *stochastic heterogeneity*. Countries also differ with regard to their demographic and economic compositions, preferences, and technologies, leading to heterogeneity in the way shocks and monetary policy are propagated (Mihov, 2001). Additionally, there is *policy heterogeneity*, referring to different economies introducing distinct policies and regulation (Jondeau and Sahuc, 2008). Even though countries in the euro area face a common monetary policy, this policy is then propagated to the member countries, interacting with the structural features of the different economies.²

This paper studies how the interconnectedness of commercial banks – as a specific aspect of *structural heterogeneity* – can account for the heterogeneous effects of monetary policy in the euro area. Recent economic theory suggests that increased risk sharing among banks through a well-functioning interbank market attenuates the effects of monetary policy in the US (Barattieri et al., 2018). The underlying argument is that if banks can securitize and trade their loan portfolios with other financial institutions, this reduces their sensitivity to changes in the interest rate, thereby attenuating the effects of monetary policy on the supply of loans (Altunbas et al., 2009).

While Barattieri et al. (2018) also address bank interconnectedness and monetary policy transmission in the euro area, their analysis does not account for the endogeneity of monetary policy nor it details how this can lead to heterogeneous responses. Our paper aims at filling this gap by expanding their work on the euro area. The role of bank interconnectedness in the transmission of monetary policy in the euro area is not only scarcely studied but the structure of the euro area also provides an excellent laboratory to study how a common monetary policy affects a heterogeneous set of economies. To exploit this structure, we assemble a panel data set for the 11 original members of the euro area and Greece, including different types of loans, a measure of bank interconnectedness, and various control variables. Finally, we supplement it with a series of exogenous monetary policy shocks for the euro area.

While there are many different readily available shock series for the US, this is not the case for the euro area. As one of the first, we use the newly launched Euro Area Monetary Policy Event-Study Database (EA-MPD, Altavilla et al., 2019) for constructing an exogenous monetary policy shock measure. The EA-MPD comprises intra-day price changes of a number of financial instruments around ECB policy announcements. This allows us to identify monetary policy shocks via changes in EONIA swaps prices and German bond rates. By estimating local projections, we assess the effects of monetary policy and its interaction with interconnectedness on the supply of loans. Finally, impulse response functions allow us to better understand the path of the effects and get a more detailed picture of the question at stake.

We find that differences in bank interconnectedness result in heterogeneous responses to monetary policy in the euro area. More precisely, we show that low degrees of bank interconnectedness are associated with a greater sensitivity of the loan supply to monetary policy shocks, whereas higher degrees of bank interconnectedness attenuate the effect. Moreover, we observe that loans in highly interconnected countries may increase after a contractionary shock, possibly due to a reallocation of loans from highly interconnected countries to less-interconnected countries. On the other hand, while both cross-country and over-time

²Hafemann and Tillman (2017); Burriel and Galesi (2018), for instance, show that the ECB’s monetary policy actions have very different effects on the member countries of the European Monetary Union (EMU).

variation of bank interconnectedness appear to play a role, cross-country variation is found to be the dominant factor. These findings are robust to the use of alternative shock measures, the inclusion of a variety of real and financial control variables, and the use of alternative sub-samples of the panel.

Our paper is structured as follows. Section 2 gives a brief overview of the literature and maps our paper within the existing research. Section 3 introduces the theory behind our hypothesis and highlights how bank interconnectedness affects monetary policy transmission. Section 4 and 5 provide a detailed description of our econometric approach and the data used throughout this paper. Sections 6 and 7 present and discuss our empirical results and perform additional robustness checks. We conclude by summarizing the most important findings and suggesting future lines of research.

2 Literature

Our research relates to different strands of literature. Specifically, it extends the work of Barattieri et al. (2018), who study the interaction between interconnectedness of banks and the transmission of monetary policy in the US, to the euro area. Barattieri et al. (2018) develop a theoretical model to explain how changes in the interest rate affect banks' lending decisions and how these are altered if banks can trade with each other in the inter-bank market. While they briefly address the case of the euro area, they do so without accounting for the endogenous nature of monetary policy. Hence, we include an analysis of how a common monetary policy affects countries in the euro area heterogeneously through this channel.

More generally, our paper draws on the standard monetary policy transmission literature. Boivin et al. (2010) and Beck et al. (2014) provide an overview of the channels through which monetary policy is transmitted and identify the interest rate channel and the credit channel as the two main mechanisms. Bernanke and Gertler (1995) expand on the credit channel, dividing it further into a balance sheet channel and a bank lending channel. The key components of the balance sheet channel, namely floating rate contracts, are explored in greater detail by Ippolito et al. (2018). They argue that the balance sheet of firms is affected by monetary policy through existing loans and mortgages which change the value of the collateral that can be posted by firms and households in order to obtain new loans. The bank lending channel is explored by Borio and Gambacorta (2017) who find that – particularly in recent years – there has been a modest but positive response of lending to a decrease in interest rates. This is confirmed by Altunbas et al. (2009) who provide an analysis of loan supply in the euro area. Kashyap and Stein (2000) further note that smaller banks, which are financed mostly by deposits and equity, exhibit stronger responses to a monetary tightening than large banks. Ciccarelli et al. (2015) provide new empirical evidence for the existence of the credit channel. Addressing the supply and demand effects of monetary policy on loans, they find that changes in the amount of loans provided by banks are mostly driven by supply rather than demand.

Furthermore, we touch upon work related to the heterogeneous effects of monetary policy in the euro area. Ciccarelli et al. (2013), for instance, show that conventional monetary policy is significantly more effective in European countries which are in financial distress. Similarly, Mihov (2001) reports highly heterogeneous effects of monetary policy across European countries depending on the size of their national manufacturing sectors, their loan-to-liability ratio and the health of their banking systems. Hafemann and Tillman (2017) and Boeckx et al. (2014) reach similar conclusions, emphasizing the role of national banking systems and, more generally, the lending channel in generating heterogeneity in monetary policy transmission. Burriel and Galesi (2018) – using a global VAR – show that unconventional monetary policy of the ECB has very heterogeneous effects on the different member countries. A main driver of this heterogeneity, they argue, is the soundness of the different financial systems.

The literature relating bank interconnectedness and monetary policy is sparse. Liu et al. (2015) and Brunetti et al. (2019) provide an overview of the phenomenon of bank interconnectedness and analyze its development over time. The former highlight the importance of bank interconnectedness for risk diversification. The latter trace the changes in bank interconnectedness in the euro area during the crisis. Ehrmann and Worms

(2004) look at the case of bank networks in Germany, relating them to monetary policy transmission. They find that in Germany, small banks often have access to interbank lending through a larger head institution, which allows them to manage their funds more efficiently and to mitigate the adverse effects of monetary policy on their portfolio. Overall, however, the literature has mostly been concerned with the adverse effects of bank interconnectedness in terms of contagion and in the context of financial crises (see for instance Cai et al., 2018; Gropp et al., 2006).

Finally, we touch upon the identification of exogenous monetary policy shocks – in particular in the euro area. Ramey (2016) provides an overview of different approaches, such as the narrative approach³ introduced by Romer and Romer (2004), the standard VAR or the augmented VAR techniques, introduced by Bernanke et al. (2005). The most common identification strategy in the literature is the estimation of a structural vector auto-regressive model (SVAR) based on short-term restrictions⁴ as pioneered by Sims (1980). A rather novel approach is to make use of high-frequency financial data (see for instance Kuttner, 2001; Mertens and Ravn, 2013). Gertler and Karadi (2015) use high-frequency financial data as an instrument in a proxy SVAR framework for the USA. Regarding the euro area, Gürkaynak et al. (2005) and Miranda-Agrippino and Ricco (2015) have noted that monetary policy announcements in the euro area entail both an information component and a "pure shock" component. As a way to separate the two, Jarociński and Karadi (2018) apply sign restrictions, whereas Altavilla et al. (2019) use a factor model to decompose monetary policy shocks into four finely-grained components to capture effects on short-term and long-term rates.

3 Theory

3.1 Monetary policy transmission mechanisms

Monetary policy is generally thought of as being transmitted via the interest rate and the credit channel (see for instance Boivin et al., 2010; Beck et al., 2014). The interest rate channel describes how changes in the nominal interest rate, i , induce changes in the real interest rate, r , due to the presence of nominal rigidities which prevent prices from adjusting one to one with the nominal interest rate (Galí, 2015). Changes in the real rate, in turn, alter investment, consumption, and savings decisions, thereby affecting real economic activity.

The credit channel can be seen as an amplifier of the effects of the interest channel. It emphasizes the role of banks as the suppliers of credit in the economy. The credit channel is often split further into a bank lending channel and a balance sheet channel (Boivin et al., 2010). The bank lending channel operates via the liquidity positions of banks. In this view, interest rate hikes make it more costly for banks to lend, forcing them to cut down on credit (Kashyap and Stein, 1995). The balance sheet channel, by contrast, stresses the importance of the asset value positions of the households and enterprises demanding credit (Bernanke and Gertler, 1995). A key underlying assumption of this view is the presence of asymmetric information in the credit market, which makes it necessary for borrowers to post their assets as collateral in order to obtain a loan. It is further presumed that the agents rely on credit financing and that the firms regard bank lending and external financing (i.e. via commercial papers) as imperfect substitutes. In this setting, an interest rate hike reduces the value of the collateral and the creditworthiness of the borrowers. Banks respond to this by contracting their loan supply.

³The narrative approach consists of identifying a shock by recording the change in the Federal Funds Rate (FFR) around Federal Open Market Committee (FOMC) announcements and using Greenbook Forecasts to isolate the unexpected component of those changes.

⁴Short-term restrictions assume that certain variables respond to shocks only with a lag.

3.2 Model

This section formalizes the argument presented in the previous paragraph in an economic model. The model was suggested by Barattieri et al. (2018) for the case of the US but is equally applicable to the euro area.⁵ The set-up consists of a two-period framework ($t = 0, 1$) and three types of actors: Banks, savers and entrepreneurs. Banks act as intermediaries between savers and entrepreneurs (borrowers). In effect, they store the deposits of the savers in $t = 0$ returning them with interest r_d in $t = 1$. They further lend to entrepreneurs in $t = 0$ reclaiming the loans with interest r in $t = 1$ and finally, they also hold money m . The entrepreneurs, on the other hand, can choose between a safe project with a certain return of 1 and a risky project, offering returns $R > 2$ and 0 with equal probabilities, thus generating an expected return > 1 . In case of success, entrepreneurs pay back the principal and the interest of their loan, $(1 + r(I))I_r$. In case of failure, the bank seizes the entrepreneur's assets A . The assets are of no use to the bank, but the seizure of the assets generates a utility loss to the entrepreneurs.

Since all the bank's business is assumed to be financed via deposits, banks need to induce entrepreneurs to invest in the safe project. Only then it is ensured that entrepreneurs can repay their loans and banks can pay back their savers in $t = 1$. Although the banks have no power over the entrepreneurs' use of funds, they can choose the overall amount of funds they make available to the entrepreneurs. Knowing that the entrepreneurs will choose among projects according to their expected return, the banks can restrict I_r such that entrepreneurs will have enough 'skin in the game' and will never find it optimal to invest in the risky project. Equation 3.1 states that the entrepreneur prefers to invest in the safe project whenever the expected return of investing in the risky project is smaller or equal to the return of the safe option (which is 0).

$$0.5[R - (1 + r(I))]I_r + 0.5(0 - A) \leq 0 \Rightarrow I_r \leq \frac{A}{R - (1 + r(I))} = \frac{A}{R - 1} \quad (3.1)$$

The bank hence sets I_r such that equation 3.1 holds and all entrepreneurs choose to invest in the safe project. Note that in this equilibrium, the interest rates are $r_d = 0$ for savers and $r(I) = 0$ for borrowers, respectively. In other words, if all entrepreneurs implement the safe project and pay back the amount they have borrowed, the banks will simply transfer the money they get back to the savers.

Equation 3.1 further reveals how monetary policy is transmitted in our model economy. Contractionary (expansionary) monetary policy reduces (raises) the value of the entrepreneurs' collateral, A . As a response, banks react by lowering (increasing) the amount of loans I_r . This implies that bank lending is sensitive to changes in monetary policy:

$$\frac{\partial I}{\partial A} = \frac{1}{R - 1} > 0 \quad (3.2)$$

Assuming that the entrepreneurs' risks are correlated within one bank but uncorrelated with the risky projects of other banks (or at least partially correlated), bank interconnectedness provides opportunities for risk sharing. In other words, interconnectedness allows banks to securitize their loan portfolios and trade the resulting securities among each other.

The model predicts that banks eventually end up selling their entire portfolio of loans and buying a perfectly diversified portfolio with loans from all other banks in the market. If this is the case, defaults of individual entrepreneurs implementing the risky project no longer affect the banks directly. As a result, banks no longer need to restrict the credit supply as a response to changes in the interest rate. In fact, the diversified portfolio of risky loans offers banks a return that is high enough to safely pay back savers (even with a positive interest rate $r_d > 0$). Hence, in the presence of interconnectedness, banks become insensitive to

⁵See section C in the Appendix for a more detailed outline of the model.

monetary policy as the value of the entrepreneurs' collateral does no longer play a role:

$$I = 1 \Rightarrow \frac{\partial I}{\partial A} = 0 \quad (3.3)$$

To conclude, bank interconnectedness can be expected to attenuate the real effects of monetary policy transmission. This is not to say that monetary policy becomes ineffective in the presence of an efficient interbank market. The interest rate channel is still at work. In fact, assuming that only a fraction λ of banks are interconnected or that banks only trade a share λ of their loans, the aggregate "strength" of the balance sheet channel mechanism is given by:

$$\frac{\partial I}{\partial A} = (1 - \lambda) \frac{1}{R - 1} + \lambda \cdot 0 \quad (3.4)$$

Note that the sensitivity of banks to changes in the interest rate is decreasing in the fraction of banks participating in the interbank market, or more generally, decreasing in the degree of interconnectedness.

The underlying assumptions of the model have partly been tested by other studies in the literature. Carstensen et al. (2009) and Nocera and Roma (2017) confirm that in the euro area, asset values⁶, respond to changes in monetary policy. Altunbas et al. (2009) find evidence for securitization activities in Europe after the introduction of the euro. Freixas and Jorge (2008) build a theoretical model in which they show that informational frictions in the interbank market induce credit rationing. A well-functioning interbank market, by contrast, can be expected to reduce the rationing and thereby weaken the transmission of monetary policy shocks.

4 Econometric approach

The theoretical model predicts that the response of bank lending to monetary policy is attenuated whenever banks are highly interconnected. To test this empirically, we develop a strategy for estimating the effects of monetary policy on lending and an approach to identifying the exogenous component of monetary policy.

4.1 Specification

We wish to estimate the heterogeneous responses of loans in the eleven original euro-zone countries plus Greece to a unique monetary policy shock. The empirical specification we use to do so is based on local projections as suggested by Jordà (2005). The idea behind local projections is simple. We regress an outcome variable of interest on various dependent variables including a monetary policy shock. Progressively, the dependent variable is moved into the future to obtain the over-time response of the outcome variable to a monetary policy shock. For several reasons, the standard approach to study these effects, using a vector autoregression (VAR) and estimating impulse responses, is not applicable in our case. Including control variables, this VAR model would become difficult to estimate with precision since the ratio of covariates to the number of observations per equation would be unreasonably large. Second, the fact that we want to distinguish the effects of monetary policy depending on the degree of interconnectedness calls for an interaction term. This can be implemented in the VAR but it unnecessarily complicates the generation of impulse responses. Lastly, it is not entirely clear whether a VAR captures the actual data-generating process of loans. If the VAR is misspecified, the specification errors are compounded at every horizon of the impulse response and the results are likely to be incorrect (Ramey, 2016).

Contrary to VARs, local projections allow for the estimation of impulse responses without the need to specify and estimate a multivariate dynamic system of equations (Bouis et al., 2016). Among others, Stock and Watson (2007) and Ramey (2016) have advocated this method is more robust to misspecifications, which

⁶Carstensen et al. (2009) specifically study house prices in the euro area.

makes it a flexible alternative to standard VAR models. Extracting impulse responses from local projections requires the estimation of a number of OLS regressions in a similar fashion to estimating direct forecasts. For this purpose, we estimate:

$$y_{i,t+h} = \beta_1^{(h)} MP_t + \beta_2^{(h)} IC_{i,t} + \beta_3^{(h)} MP_t \times IC_{i,t} + \bar{X}_{i,t} \gamma_1^{(h)} + MP_t \times \bar{X}_{i,t} \gamma_2^{(h)} + fe + \varepsilon_{i,t+h} \quad (4.1)$$

for the horizon $h = 1, 2, \dots, H$. Since we work with monthly data, we set $H = 24$ months. The dependent variable, $y_{i,t+h}$, is the logarithm of household loans, corporate loans, or the sum of both. MP_t is our measure of monetary policy surprises. Bank interconnectedness is captured by $IC_{i,t}$, the demeaned control variables are collected in $\bar{X}_{i,t}$. We allow for fixed effects across countries, months, and years. Whereas the shock is measured at the euro-area level, outcome variables and our measure of interconnectedness are recorded for each period, t , and each country i ⁷.

We interact our monetary policy shock with the measure of interconnectedness. This term captures the difference in the reaction to a monetary policy shock between countries and periods that display a highly connected banking sector and countries and periods with low interconnectedness. Our monetary policy shock is exogenous by construction and, therefore, does not require the inclusion of any control variables. The degree of interconnectedness of a country's banking sector at a given point in time, on the other hand, may be a function of the financial and economic conditions. That is to say, if there exist variables that are correlated with both the outcome variable (loan volume), and the degree of interconnectedness, the coefficients may be biased. We therefore include additional control variables and interact them with the monetary policy variable to ensure that the potential endogeneity of bank interconnectedness is accounted for.

Our benchmark model includes three control variables that account for potential confounders: Financial distress, the log of GDP per capita, and a time trend. *Financial distress* captures the state of the financial system in each country and point in time. If banks are stressed, this is likely to be reflected not just in a change in their interbank trading but also in the volume of loans they give out. *GDP per capita* captures real economic fluctuations, which affect the demand for loans (Blundell-Wignall et al., 1992). At the same time, we also observe that bank interconnectedness tends to be higher in countries with a high GDP per capita (core countries) and lower in countries with lower levels of GDP per capita (periphery countries, see figure A2.2)⁸. We include a *time trend* to capture linearities in the evolution of loans. Interacting the trend with MP_t allows us to control for a general change of monetary policy effectiveness that is not due to differences in bank interconnectedness (Barattieri et al., 2018).

In terms of specification, although lags of the dependent variable are often included when doing local projections, we abstract from this convention due to our inclusion of time and country fixed effects. Including both lags and fixed effects would leave our estimation strategy exposed to the Nickell bias (Nickell, 1981). We demean our control variables such that the interpretation of β_1 is the effect of a monetary policy shock when $IC_{i,t}$ is set to 0 and the controls are at their mean value.⁹ Finally, we use Newey-West standard errors to account for the heteroskedasticity and autocorrelation of the standard errors.

Impulse responses for local projections are constructed by plotting the marginal effect of MP_t for each horizon $h = 1, 2, \dots, H$. Impulse responses of local projections are heavily parametrized, which can make them appear jagged even if the underlying data-generating process is relatively smooth (Barnichon and Brownlees, 2018). To mitigate this problem, we estimate the impulse responses for the benchmark model which includes a trend, financial distress, and GDP per capita as controls.

⁷Note that $IC_{i,t}$ corresponds to the parameter λ in the theoretical model presented in section 3.2.

⁸Countries defined as core in the sample are Austria, Belgium, Finland, France, Germany, Luxembourg and Netherlands. Greece, Ireland, Italy, Portugal and Spain are categorized as periphery.

⁹The minimum IC in our sample is close zero, with Greece exhibiting an IC of 0.014 in December 2016.

The marginal effect of a monetary policy surprise on the dependent variable is given by:

$$\frac{\partial y_{i,t+h}}{\partial MP_t} = \hat{\beta}_1^{(h)} + \hat{\beta}_3^{(h)} IC_{i,t} \quad (4.2)$$

Given that we demean the control variables, they do not appear in the marginal effect. We construct 90% confidence intervals using Newey-West standard errors.¹⁰ To distinguish the reaction of $y_{i,t+h}$ to a monetary policy shock in cases of low and high interconnectedness, we plot the response for IC at the 25th and at the 75th percentiles. Equation 4.2 corresponds to a one percentage point unexpected change in the policy rate. This, however, is a very uncommon magnitude for both a contractionary or expansionary shock. Hence, we plot the response to a shock of 1 basis point to make it easier to convert the response to a more reasonable magnitude.

4.2 Monetary policy shock identification

The literature identifies three reasons why an exogenous monetary policy variable (MP_t) needs to be constructed for the equations presented above. First, the conduct of monetary policy, and therefore the policy rate, is an endogenous response to prevailing economic conditions. For instance, when inflation is below the target level or if the output gap is negative, the central bank is likely to lower interest rates (Froyen, 1974). A second challenge is that monetary policy may not only affect the current policy rate but also lead to changes in agents' expectations about the future path of the interest rate (Zhang, 2018). In particular, the period studied in this paper is characterized by numerous instances of forward guidance, i.e. attempts by the central bank to impact people's expectations about the path of the interest rate. Merely including the level or the changes of the interest rate would therefore not capture forward guidance. A third reason is the fact that monetary policy decisions and announcements may reveal information about the current and future states of the economy which can have contractionary or expansionary effects by themselves (Jarociński and Karadi, 2018). As a response to the central bank's action or inaction, the private sector updates its beliefs about the state of the economy and adapts its behavior accordingly. Hence, simply using changes in an interest rate as a monetary policy shock would involve endogeneity issues and would result in inappropriate conclusions.

Many approaches have been suggested to extract the exogenous component of monetary policy. Starting with Sims (1980), a commonly used approach to identify the monetary policy shock consists of using a vector autoregression with a Cholesky decomposition and sign restrictions (see Boeckx et al., 2014; Ciccarelli et al., 2013; Barattieri et al., 2016). This approach may be reasonable if the variables – such as output or inflation – respond to MP_t only with a lag. However, it has repeatedly been shown that loans react relatively fast to monetary policy (see for instance Kakes and Sturm, 2002).

A more recent approach that is tailored to the purpose of our study is the use of high-frequency data as advocated by Kuttner (2001), Cochrane and Piazzesi (2002), and Mertens and Ravn (2013). The central idea of this method is to use the changes in short-term interest rate futures around monetary policy announcements as an instrument for an endogenous longer-term spot rate (Stock and Watson, 2018). The fitted values of the first stage regression are then introduced in the local projections as an exogenous measure of monetary policy surprises. Under the efficient market hypothesis, which states that prices of financial products reflect all information available to the market, price changes of futures or other financial derivatives can be used to identify the unexpected component of monetary policy. That is, price changes within a narrow window around the monetary policy announcement arise from unanticipated actions of the central bank and are, hence, orthogonal to market participants' information set.

We obtain our exogenous monetary policy shock by using a high-frequency identification strategy combined

¹⁰A detailed explanation of how we construct the confidence bands can be found in the Appendix in section D. The method is slightly more involved than usual since we include an interaction term.

with an instrumental-variable approach. The variable we instrument is the change in the yield of 2-year German bonds around the ECB’s policy announcement window, which is customarily used as the policy variable in the literature (Ramey, 2016; Jarociński and Karadi, 2018). In particular, the price change around the announcement window is computed as the difference between the median rate of a ten-minute interval preceding the press release which takes place at 13:45 and the median rate a the ten-minute interval succeeding the press conference which finishes at 15:30. The exact timeline is depicted in figure A1.1 in the Appendix.

One might be tempted to directly use the price change of futures as an exogenous monetary policy shock. However, Stock and Watson (2018) highlight that these changes should not be considered the monetary shocks themselves but rather an instrument for the actual shock. This peculiarity arises from the fact that the futures price changes only capture the part of the shock that affects short-term yield and that they are often subject to measurement error.

The instrument Z_t constitutes a good instrument for the policy variable if it satisfies the following conditions:

1. $\mathbb{E}(MP_t Z_t) \neq 0$ (*relevance*)
2. $\mathbb{E}(\varepsilon_{j,t} Z_t) = 0$ where $\varepsilon_{j,t}$ is some other shock to the economy (*contemporaneous exogeneity*)
3. $\mathbb{E}(\varepsilon_{t+h} Z_t) = 0$ for $h \neq 0$ where ε_{t+h} contains all shocks (including MP_t) (*lead-lag exogeneity*)

The first two conditions are the standard relevance and exogeneity conditions. The third condition requires the instruments to be uncorrelated with all other shocks at all lags and leads. In practical terms, this is interpreted as the shocks not being predictable by their own past values. Regarding condition 2, it is unlikely that other shocks take place in the small window of time we consider in our analysis. More importantly, as Gertler and Karadi (2015) argue, since monetary policy decisions are usually not affected by other economic news that take place the same day of the announcement, the price change is orthogonal to all other possible shocks.¹¹ Hence, it is reasonable to assume that the change within the window is only due to the announcement itself. Lastly, our first stage regression results indicate that our instrument is indeed relevant with an F-value of 109.

One practical limitation is that yield changes are recorded on a daily basis whereas our local projections are conducted with monthly data. We therefore identify the shock by regressing the daily bond yield change on the daily EONIA swap price change and aggregate the resulting fitted values to a monthly measure. For this purpose we follow the approach of Romer and Romer (2004) which entails summing up all shocks that take place within each month. Gertler and Karadi (2015) use a different aggregation method which consists of summing, for each day, all the shocks that happened in the previous 31 days and then taking the average of all days within each month. While the results in the local projections are not substantially different, Ramey (2016) highlights that the latter produces non-mean zero shocks which are also serially correlated.

Some caveats of our shock-identification strategy are worth mentioning. The first issue to address is the monthly aggregation of data. While it is hardly ever the case, it can happen that positive and negative shocks within a month cancel each other out. However, due to the fact that this is a general problem in the literature (which has only partially been resolved) and given the robustness of our results to alternative aggregation methods, we decide to stick to the Romer and Romer (2004) approach. Second, it has recently been shown that the standard identification method captures both pure monetary policy shocks and information shocks (Miranda-Agrippino and Ricco, 2015). Whereas the former relate to the actual changes in monetary policy, the latter refer to the implicit information about – and revealed view on – the state of the economy contained in the decisions of the bank. The two shocks tend to occur simultaneously and, in particular, they tend to have opposite effects on the prices of financial assets. This blending of shocks could again result in the effects canceling each other out. For this reason, we also include in section 7 a specification in which we use a

¹¹The argument here is that the policy decision is taken prior to the actual announcement and is therefore unaffected by events happening on the day of the announcement.

measure of monetary policy shocks developed by Jarociński and Karadi (2018) that detracts all informational components of the change in the rate.

5 Data

To assess how interconnectedness affects the transmission of monetary policy, we construct an exogenous measure of monetary policy surprises at the euro area level and a measure of interconnectedness of the banking industry at the country level. We identify the key dependent variables, and lastly, define a set of controls. Using these, we construct a panel for the 11 original euro-area countries and Greece from January 2003 to September 2018.¹²

5.1 Monetary policy shock

As explained in the previous section, we obtain our exogenous monetary policy shock by using a high-frequency identification strategy combined with an instrumental-variable approach. The variable we instrument is the change in the yield of 2-year German bonds around the ECB’s policy announcement window, which is customarily used as the policy variable in the literature (Ramey, 2016; Jarociński and Karadi, 2018). This series we obtained from the EA-MPD mentioned before, constructed by Altavilla et al. (2019). As an instrument, we use the change in the yield of the three-months swaps of the Euro OverNight Index Average (EONIA) around the policy announcement window described above. This series is also obtained from the EA-MPD. We define our daily shock measure as the fitted values of the regression of the 2-year German bond yield changes on the changes in the 3-month EONIA swap. Finally, our monthly shock measure is computed as the monthly sum of the daily shocks.

The final shock series is plotted in figure 5.1. As expected, the series oscillates around 0 with the biggest shock occurring towards the end of 2001. This is related to the aftermath of the 9/11 terrorist attack where the ECB followed the Fed in reducing the interest rate to deal with increased uncertainty (Altavilla et al., 2019). Additionally, October and November 2008 and several months during 2011 exhibit great volatility. These two episodes correspond to the 2008 financial crisis and the European sovereign debt crisis, respectively. Hence, in the presence of financial turmoil, the unexpected component of monetary policy decisions appears to be greater. 2016 displays a set of positive (contractionary) shocks to the interest rate, which may at first sight appear to be counter-intuitive given that the ECB was actually following an expansionary strategy at the time. The spikes can, however, be rationalized in that markets expected greater reductions in the interest rate (more generally, an even stronger expansionary monetary policy) than the ones that were actually implemented.

Table 5.1 shows the summary statistics for our monetary policy shock variable, measured in percentage points. The mean is very close to 0, as would be expected, and the standard deviation is 3 basis points.

Table 5.1: Summary statistics monetary policy shock

	Mean	Standard deviation	Minimum	Maximum
<i>MP</i> in %	0.001068	0.032926	-0.236971	0.135903

¹²The panel starts in 2003 because country-level data of loans is available at the ECB Warehouse only since January 2003. However, the use of the period before 2003 is complicated by the fact that intraday data on EONIA swaps is noisy from the creation of the EMU until the end of 2001 (Altavilla et al., 2019).



Figure 5.1: Monetary policy shock measure

5.2 Bank interconnectedness

A measure for bank interconnectedness should capture how integrated banks in a given country are with other banks, either local and foreign.¹³ The literature identifies two main approaches for measuring interconnectedness: A ‘physical’ approach, which defines interconnectedness by the importance of banks in other banks’ balance sheets, and a ‘market’ approach, which relies on a measure of partial correlation among the credit default swap (CDS) spreads of banks (see for instance Liu et al., 2015; Brunetti et al., 2019).

We proceed with the former approach as this may be better suited to capture real, risk-sharing, interactions among banks which is exactly what our theoretical model is based on. More precisely, we follow Barattieri et al. (2018) and construct our measure as the percentage of assets that have a counterpart within the banking system. In other words, we consider assets which correspond to loans to other banks.¹⁴ We use the monthly volume of loans from Monetary Financial Institutions (MFIs) to other MFIs and the monthly level of total assets of MFIs. Both series are aggregated at the country level and were obtained from the ECB Statistical Data Warehouse.

Figures A2.1 and A2.2 in the Appendix illustrate that there is significant heterogeneity in interconnectedness both across countries and over time.¹⁵ We can see that there is no clear trend in the degree of interconnectedness over time nor is there a common pattern during the periods of crises. Table A2.1 presents the mean over the sample period, which also differs significantly across countries.

5.3 Dependent variables

To test the direct implications of the theoretical model, we need to capture how lending is affected by the degree of interconnectedness of banks. The dependent variables of interest are thus the stock of loans to households, to non-financial corporations, and the sum of the two, to which we refer to as total loans. All three series were obtained from the ECB Statistical Data Warehouse. We take the logs of the variables to account for the non-stationary nature of the volume of loans and to facilitate the interpretation. Figure A2.3 in the Appendix plots the evolution of total loans across different countries. Figures A2.4 and A2.5, by contrast, show the evolution of total loans across core and periphery countries. Lastly, table A2.1 in the

¹³Assuming that risk sharing takes place independently of the origin of the connected banks.

¹⁴We look at interconnectedness from the perspective of the asset side of the balance sheet as this would reflect how much risk sharing there is.

¹⁵Note that in 2005 the Netherlands switched their accounting regime from Local GAAP to IFRS which resulted in a revaluation of assets (De Nederlandsche Bank, 2015). As a result, there is a jump in the interconnectedness measure of Netherlands. This, however, does not affect our results as regressions excluding the Netherlands showed.

Appendix features the country means of household and corporate loans.¹⁶ We can see in the graphs that core countries mostly exhibit an upward trend throughout the whole period, slowing down a bit after the financial crisis, while periphery countries experience a significant drop in the volume of loans throughout the entire period after the financial crisis up to 2018.

5.4 Controls

Since our monetary policy measure is exogenous by construction, we only need to control for the potential endogeneity of bank interconnectedness. That is, we need to identify variables that are likely to be correlated both with the volume of loans and bank interconnectedness and which would, if not accounted for, lead to a bias in the coefficients. Moreover, adding controls might reduce the standard deviations of the coefficients, improving the precision of the confidence intervals.

For our benchmark model, we include as controls only the *log of GDP per capita* (OECD), a measure of *financial distress* (ECB Data Warehouse), and a *trend*. All controls are added individually and interacted with monetary policy. The reduced amount of controls is desirable for obtaining smoother impulse response functions. Nonetheless, we also test the exogeneity of our interconnectedness measure by adding more controls in the robustness checks section. The first additional control we introduce is a variable that accounts for trade integration, arguing that countries with interconnected banking systems are likely to be interconnected also in other dimensions. Trade integration is computed as the value of exports plus imports (OECD) over GDP (Eurostat). Following Barattieri et al. (2016), who present a model that explains the changes in bank interconnectedness with the level of leverage of the banking sector, we include average leverage of the countries' banking sectors as a control variable. Also, since De Masi and Gallegati (2012) find that in Italy large banks are significantly more connected with other banks than small banks, we decide to add the average size of banks in each country as a control variable. Together with the evidence by Kakes and Sturm (2002), who show that the size of banks significantly affects how banks respond to monetary policy shocks in terms of loan restrictions, this indicates that the average size of banks within one country may bias our *IC* coefficient. Finally, we also control for the aggregate size of a country's banking industry by including the amount of total assets of the banking industry as a fraction of GDP. The data on these variables is obtained or constructed using data from the ECB Data Warehouse.

All control variables are de-measured such that the coefficients of *MP* and $MP \times IC$ depict the effects of monetary policy and interconnectedness at the mean level of controls, giving the findings a more natural interpretation. We include a full description of all data sources in table A0.1 in the Appendix.

6 Results

6.1 Panel analysis

We run the regressions for our benchmark model for 12 euro-area countries using country, year, and month fixed effects. Below we present the regression output for our local projections at lag 3. That is, in a setting in which we observe the effect of a monetary policy shock at time t on the volume of loans three months later. One quarter provides a reasonable time horizon to study: while the effect is already clearly established, three lags constitute a lower bound of the reaction as will be clear from the impulse-response plots. The lag was also chosen based on the Akaike Information Criterion.

Specifically, we are interested in the monetary policy coefficient (referred to as *MP* in the tables) and, most importantly, the interaction between monetary policy and bank interconnectedness ($MP \times IC$ in the tables).

¹⁶Greece experienced a rather substantial increase in loans in mid-2010. While this is most probably associated to the Greek debt crisis which was in full swing in summer 2010, we are not able to identify the exact reason for this jump. However, robustness checks will show that our results are robust to the exclusion of Greece.

From a theoretical point of view, the first coefficient is expected to be negative if contractionary monetary policy surprises (increases in the interest rate) have a negative impact on loans. For the interaction term, on the other hand, we expect to find a positive coefficient since – according to the theoretical model – a higher level of interconnectedness should hamper the effect of monetary policy on bank lending.

Table 6.1: Benchmark model

	log(total)	log(total)	log(total)	log(CL)	log(HHL)
MP_{t-3}	0.056 (0.072)	-0.491*** (0.183)	-0.475** (0.204)	-0.478** (0.237)	-0.457** (0.216)
IC_{t-3}		0.650*** (0.173)	1.121*** (0.143)	1.320*** (0.191)	0.981*** (0.152)
$MP_{t-3} \times IC_{t-3}$		3.292*** (0.931)	3.734*** (0.985)	3.943*** (1.129)	3.471*** (1.078)
Fin. distress			0.284*** (0.076)	0.226** (0.101)	0.329*** (0.070)
$MP_{t-3} \times \text{Fin. distress}_{t-3}$			-0.482 (0.629)	-0.831 (0.764)	-0.122 (0.653)
$\log(\text{GDPpc})_{t-3}$			-1.060*** (0.110)	-1.163*** (0.166)	-1.055*** (0.091)
$MP_{t-3} \times \log(\text{GDPpc})_{t-3}$			-1.503 (1.851)	-1.792 (2.230)	-1.679 (1.972)
Trend	0.003*** (0.001)	0.003*** (0.001)	0.004*** (0.001)	0.003*** (0.001)	0.005*** (0.001)
$MP_{t-3} \times \text{Trend}$	0.000 (0.003)	0.001 (0.003)	0.002 (0.002)	0.002 (0.003)	0.002 (0.003)
Adj. R-squared	0.984	0.984	0.988	0.981	0.989
Observations	2268	2268	2268	2268	2268
Country FE	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes

Newey-West SE in parentheses; * $p < .10$, ** $p < .05$, *** $p < .01$

Shock in percentage points; Mean $IC = 0.167$

CL = corporate loans; HHL = household loans; total = CL + HHL

All explanatory variables except for MP and IC are demeaned

Table 6.1 displays our regression results with Newey-West standard errors in parentheses. Both the coefficient for monetary policy and the interaction term have the expected signs. The interaction term, as well as the monetary policy variable are statistically different from zero.¹⁷

The estimates can be interpreted as follows. In the third column, for instance, a 10 basis point increase¹⁸ in the interest rate leads to a decrease in total loans¹⁹ of 4.75% if the degree of interconnectedness is zero and financial distress and log GDP per capita are evaluated at their mean levels for each country. The coefficient for the interaction term is usually around 3-4 times larger – in absolute value – than the coefficient for monetary policy. This is comparable to the effects obtained by Barattieri et al. (2018) for the US. For the specific case of total loans, it would take an interconnectedness of 0.13 for the effect of monetary policy to be completely offset through this mechanism. In the case of a value lower than 0.13, monetary policy would still have its usual effect of lowering the loan volume, while in the case of an interconnectedness higher than the threshold value, the effect of monetary policy would be reversed. The measure for interconnectedness ranges from 0.014 to 0.374 for the full set of countries and periods in our data set and has a mean value of

¹⁷If not stated otherwise, our two coefficients of interest MP_t and $MP_t \times IC_{i,t}$ are jointly significant at least at the 5% level.

¹⁸As a reference, several interest rate surprises around the sovereign debt crisis in 2012 were of this magnitude. A 10 basis point hike corresponds to a shock of approximately 3 standard deviations of the MP series. In our data set, we observe 15 shocks larger than one standard deviation, 7 shocks larger than two standard deviations, and 3 shocks larger than three standard deviations. Also note that the shock series is in percentage points and the dependent variable in logarithms.

¹⁹As a reminder, total loans is the sum of corporate and household loans, it does not include loans to banks and sovereigns.

0.167. This implies that the canceling out of effects may be a plausible outcome in our sample²⁰ and that the difference in the levels of interconnectedness in the euro area could be an important source of heterogeneity in the responses to monetary policy among the different countries of the euro area.

The individual coefficient for interconnectedness indicates that countries with a higher degree of interconnectedness tend to have higher levels of loans, which may be rationalized by the fact that richer core countries tend to have more interconnected banking sectors (see figure A2.2) and higher nominal levels of lending (see table A2.1). It is worth noting that the coefficient for monetary policy in the first specification, where we have only the shock and a trend, is not significantly different from zero. This implies that if we were not to take into account interconnectedness of the banking sector, we would find no effects of monetary policy on the level of lending, which is in line with some recent findings in the literature. Borio and Gambacorta (2017) and Altunbas et al. (2009), for instance, find that, particularly in recent years, the response of lending to changes in the interest rate has been rather modest, albeit significant and with the expected negative sign. An ad-hoc explanation for this difference between their and our findings could be that both papers make use of very detailed bank-level data whereas our results build on aggregate bank-level data.

Next we turn to the impulse response functions, which we generate for our three loan variables and a monetary policy shock of one basis point. We plot the marginal effects, as explained in section 4.1, and compute two paths: one for a low level of interconnectedness, defined as the 25th percentile of the sample distribution of interconnectedness, and one for a high level, corresponding to the 75th percentile. The former value, 0.11, corresponds to countries such as Spain and Portugal, while the latter measure, 0.23, corresponds to the level of France and Austria. For the low interconnectedness case, we observe that an unexpected increase in the interest rate by 1 basis point leads to a -0.03% change in total loans after one period, which is magnified after 6 periods to -0.30% before converging back towards zero. For the case of a higher interconnectedness, a one basis point monetary policy shock, increases the loan volume by 0.33% in the first period. The effect remains positive for 15 periods before converging back to zero. Similar effects are found for the response of household and corporate loans (see figures A3.1 and A3.2 in the Appendix).

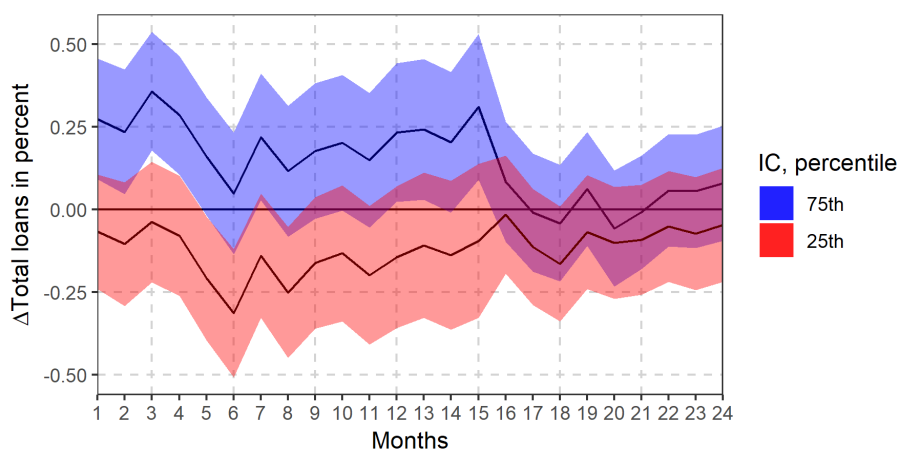


Figure 6.1: Benchmark: IRF of total loans to a one basis point increase in MP_t

All in all, the results suggest that high levels of interconnectedness may not only mitigate but even revert the effects of a contractionary monetary policy shock. It is surprising that when bank interconnectedness is high, a contractionary monetary policy appears to increase the amount of loans. This could be due to an effect similar to that described by Ehrmann and Worms (2004) who find that small banks in Germany obtain liquidity from larger ones in the event of tightening monetary policy. In that case, the loan volume increases as small banks – thanks to the additional financing – can avoid cutting down their loan supply. Analogously, the observation might reflect that in moments of liquidity shortages due to more restrictive

²⁰Note that the response after 3 months is not the maximum response. After half a year, for instance, interconnectedness would have to be much higher to offset monetary policy.

monetary policy, countries that are more interconnected – core countries – start lending to less interconnected periphery countries.²¹ This reasoning may be justified by the fact that we observe a contraction of loans when interconnectedness is low. If demand for loans remains at its previous level, then firms and households may switch from local banks to foreign, highly interconnected banks that do not decrease their loan supply, thereby *increasing* the volume of loans in countries with high interconnectedness.

Another explanation for the increase in loans after an increase in the rate could lie in the reasoning of Fabiani et al. (2018). They find that tightening monetary policy is not effective for controlling credit cycles in the context of free capital flows. Their argument states that an increase in the interest rate makes it more profitable to borrow from abroad and to give out loans in the local currency. In the context of the euro area, highly connected banks which are able to trade their loan portfolio with other banks and which are thereby unaffected by the changing value of borrowers' collateral, may borrow at a low interest rate from countries outside the euro area and forward this liquidity to households and firms.

6.2 Heterogeneous responses to a common shock

So far, we have found evidence for the hypothesis that bank interconnectedness affects the transmission of monetary policy in the euro area. We now look at the implied heterogeneous effects of a common monetary policy shock in the different countries of our sample, which vary in their individual level of *IC*. We abstract from the control variables and compute the effect on loans with the monetary policy shock and its interaction with bank interconnectedness.

Figure 6.2 illustrates how the country-specific volume of total loans is expected to respond to a contractionary shock of 1 basis point in the period where the effect is the largest (which we observe after 6 months). For each country, we plot the response for three levels of *IC*: The country-specific 10th percentile, the median, and the country-specific 90th percentile. The figure illustrates that – according to our estimates – countries with an *IC* that is high across the whole time period, such as France and Luxembourg, would not be expected to experience the standard effects of monetary policy. In fact, our model indicates that loans in these countries would instead increase when facing interest rate hikes. Most of the countries in our sample, however, would still be affected by monetary policy in the standard way, mostly at their low and median levels of interconnectedness. It is interesting to observe that at the median value of *IC* there would be extensive heterogeneity in the implied effects. For instance, as a response to a one basis point shock, our estimated model would predict an increase in loans by 0.07% for France within 6 months, while Portugal would be expected to see a decrease of -0.38% in the total outstanding loan volume.

Lastly, using again the coefficients obtained for the 6-month horizon, we compute how the different countries would theoretically be affected by the shocks in the sample given their actual degree of interconnectedness at the time of each shock. Results for the mean response of each country are displayed in figure 6.3. The mean effects of surprises in total loans range from -0.04% to 0.05%. This, once again, confirms that interconnectedness can cause sizeable differences in the responses to monetary policy across the countries of the euro area. As before, Luxembourg and France stand out as countries that had rather high levels of bank interconnectedness when shocks took place in our sample. Contrary to this, several periphery countries, but also Belgium and Finland, are expected to experience considerable decreases in their loan supply. Clearly, the implied effects are substantial. It should, however, be noted that this visualizes the mechanism studied in this paper *in isolation*. The actual, observed response of loans in the respective countries may differ since there are other channels and country-specific shocks at play.²² Nonetheless, these results indicate that bank interconnectedness can affect the transmission of monetary policy significantly.

²¹See figure A2.2 for a comparison of core-periphery interconnectedness and figures A2.4 and A2.5 for the evolution of loan volumes over time.

²²As has been argued, the average size of banks or the leverage of banks within a country can play a crucial role in determining the response of the banking sector to monetary policy.

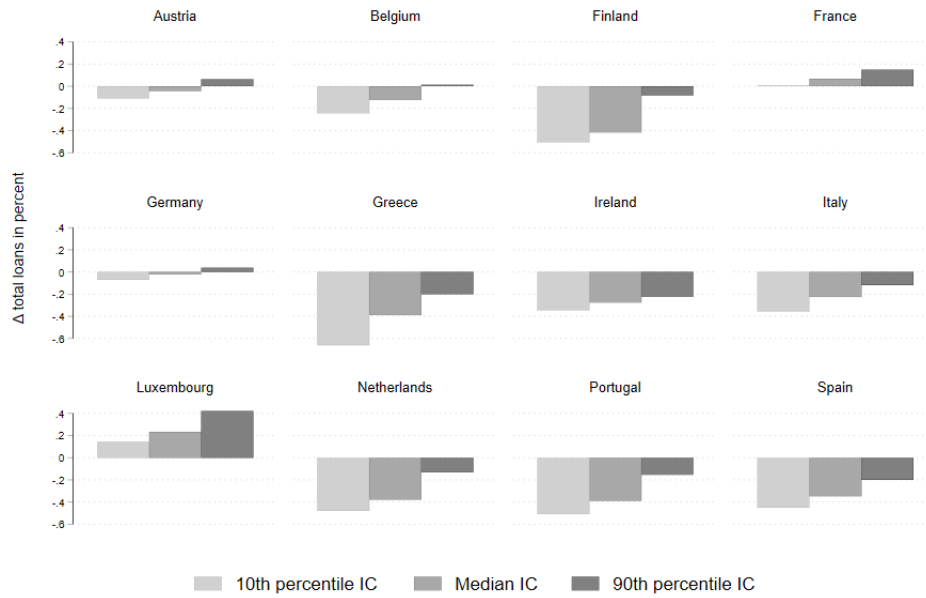


Figure 6.2: Heterogeneous response after 6 months to a common monetary policy shock of 1 basis point

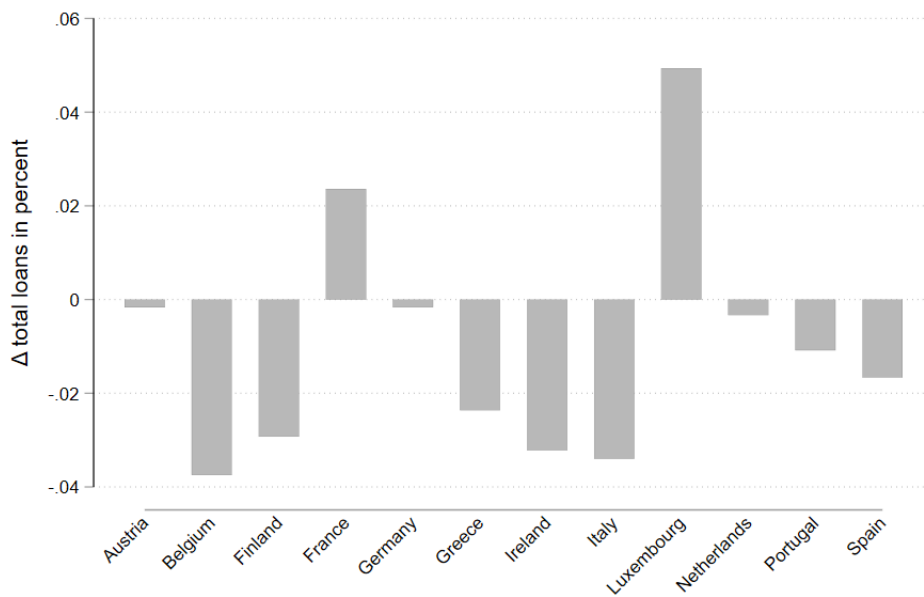


Figure 6.3: Mean effect of monetary policy shocks in the sample by country in a 6-month horizon

6.3 Disaggregation of variation in interconnectedness

The panel captures variation in interconnectedness both across countries and over time. In this subsection, we explore the role of time variation and country differences independently. To disentangle the two effects, we test additional specifications in which one of the two sources of variation is muted. This procedure allows us to study, in isolation, the effect of the two components' contribution to the overall effect.

6.3.1 Cross-country variation

We start by analyzing the extent to which cross-country variation in interconnectedness can explain the effects uncovered. To do so, we compute the mean of IC across time for each country and estimate the benchmark model in equation 4.1, replacing $IC_{i,t}$ with the newly created variable, IC_i . This essentially implies muting the over-time variation, leaving only the variation in interconnectedness across countries to explain the pattern.

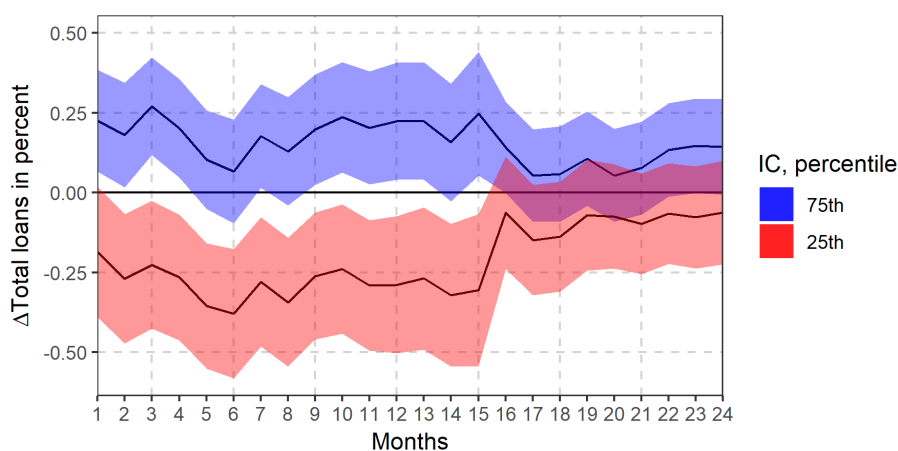


Figure 6.4: Benchmark: IRF of total loans to a one basis point increase in MP – no time variation in IC

Figure 6.4 plots the response of total loans to a one basis point increase in the interest rate.²³ We again observe a significant decrease in the supply of loans after a contractionary monetary policy shock for the case of banks being poorly interconnected. The effect is both immediate and persistent for over a year – comparable to what was documented in the previous section. It should be noted that the effect is significant at higher levels than before with more narrow confidence bands. Furthermore, loans increase in countries with high bank interconnectedness in a similar fashion as they did in the benchmark model (blue confidence bands). Similar to before, the curve is close to zero and very often not significantly different from it. As in the full panel, the effect of monetary policy vanishes and loans return to their initial level after around 16 months. In sum, the results indicate that differences in bank interconnectedness *across* countries play a crucial role in accounting for the effects described in the previous section.

6.3.2 Over-time variation

We turn to the second dimension of variation in bank interconnectedness, variation *over time*. To isolate the over-time variation, we use three different approaches. First, for each point in time, we construct a weighted average of the individual countries' interconnectedness measures.²⁴ Hence, the new measure, IC_t , only varies over time. As previously discussed (and plotted in figure A2.1), there is no clear trend of interconnectedness

²³The corresponding regression output for the response after one quarter can be found in the Appendix in table A4.1.

²⁴We weight countries' interconnectedness by bank assets in order to account for the different sizes of banking sectors in the euro area.

over time and aggregating the individual measures into one variable clearly leads to a substantial degree of heterogeneity being cancelled out. Consequently, estimating the benchmark model (equation 4.1) with IC_t instead of $IC_{i,t}$ yields similar, yet non-significant, results. Second, we investigate the question at stake by interacting country fixed effects with the monetary policy variable. This controls for country-specific responses to a monetary policy shock. The effects go again in the right direction, but the standard errors are still too large to make any serious assertions. Third, we estimate impulse responses for individual countries. The main finding continues to hold; we find little evidence that over-time variation is imperative for explaining our main results. Although most countries display an effect that goes in the expected direction, the confidence bands are generally too large to be considered conclusive evidence. Hence, while we cannot establish a clear role of over-time variation, there is also no clear evidence against it.

Finally, it has to be noted that muting over-time variation is probably more natural than muting variation across countries. Country-level regressions drastically reduce the number of observations, whereas creating an aggregate measure of interconnectedness from individual countries' interconnectedness dissipates the variation to a large degree. This may explain why we still find effects that point in the correct direction but lack significance. Overall, the major role played by cross-country variation in interconnectedness may raise concerns about the presence of additional country-specific factors which we do not account for and which are, thus, being captured by the $IC_{i,t}$ term. The following section provides robustness checks that include a number of additional controls which are meant to ensure that our effects are effectively unbiased.

7 Robustness checks

7.1 Additional control variables

Having raised the question of whether our interconnectedness measure captures other correlated variables, we test the robustness of our results by including additional controls in the model that are suggested by the literature and those which we consider relevant given their correlation with both interconnectedness and the volume of loans.

The results are presented in table A6.2. Using the logarithm of total loans as dependent variable, we progressively addition controls to the benchmark model. In the second column we include the logarithms of banks' assets and banks' size as well as leverage. In the third column, we further include a measure of trade integration and its interaction with monetary policy. The third and fourth columns present the specifications using all controls but changing the dependent variable to corporate loans and household loans, respectively. All variables are included individually and interacted with the monetary policy shock measure. It is apparent that our results are robust to alternative specifications and the sequential addition of control variables. The coefficients of our monetary policy measure and the interaction term with interconnectedness have similar magnitudes and increase only marginally when adding additional controls. The same holds for when using household loans or corporate loans as dependent variables. At the same time, the significance of our results is preserved or even increased. The absence of any large changes is not only true for the regression with a shock at $t - 3$; the impulse responses also maintain their shape and magnitude.

7.2 Alternative shock measures

We test whether our results are robust to alternative monetary policy shock measures. There are many different ways in which monetary policy shocks can be identified. Table A6.1 in the Appendix presents the benchmark model with two alternative monetary policy shock measures. Both shocks are extracted from a VAR using slightly different techniques. In column one, we follow the methodology of Gertler and Karadi (2015) and in column two we use a *pure* monetary policy shock as constructed by Jarociński and Karadi (2018).

Following Gertler and Karadi (2015), we estimate a structural VAR with external instruments. The VAR includes industrial production in the euro area, a harmonized consumer price index, the A-rated corporate bond spread²⁵, and the German 1-year bond yield as the policy instrument.²⁶ Due to the monthly frequency of the data, we estimate the model with 12 lags. We then instrument the reduced form VAR residuals of the German 1-year bond yield with the change in the EONIA 3-month swap price in the announcement window to obtain our monetary policy shock measure. For the monthly VAR, we aggregate the high-frequency price changes on announcement days into a monthly time series. We follow the approach of Gertler and Karadi (2015) and generate rolling-window averages of the surprises on any of the announcement days during the last 31 days. Our second alternative monetary policy shock measure is meant to test whether our results are sensitive to the mixing of the information shock and the pure monetary policy shock component, which Miranda-Agrippino and Ricco (2015) emphasize to be an important distinction. Using sign restrictions in a VAR, Jarociński and Karadi (2018) disentangle *pure* monetary policy shocks from *information* shocks by analyzing the high-frequency co-movement of interest rates and stock prices in a narrow window around the policy announcements. We use their *pure* monetary policy shock to test the sensitivity of our results.

Table A6.1 shows that the coefficients of interest are significant and their signs are in line with our previous findings. While the two coefficients capturing our mechanism decrease slightly in absolute terms, the cut-off interconnectedness for which monetary policy has no effect is hardly affected and stays in the range between 0.12 and 0.15. This can be interpreted as further evidence that our identification strategy is appropriate and it provides assurance that we are not ignoring important variation in the shock measure. Figure A6.1 provides evidence that the three types of shocks follow a similar path although they have been constructed using different assumptions.

7.3 Sub-samples of the panel

We run a number of additional robustness checks by dividing the panel into various sub-samples.

First, we divide the sample into core (Austria, Belgium, Finland, France, Germany, Luxembourg and Netherlands) and periphery countries (Greece, Ireland, Italy, Portugal and Spain) and re-estimate the benchmark model. Table A6.4 in the appendix shows that the signs of *MP* and *IC* are as expected in both samples. We find that both coefficients of interest are larger in absolute value for the periphery countries, but the ratio of the two is lower (0.161 as opposed to 0.214 for core), suggesting that the cutoff interconnectedness for monetary policy is lower among periphery countries. This, however, does not necessarily imply that monetary policy, as a consequence, is less effective in the periphery. In fact, the reverse may be true given that the mean value of *IC* is lower among periphery countries (0.122) than among core countries (0.199). On the other hand, the lack of significance of the interaction coefficient for the core sub-sample may be explained by the low variation of interconnectedness over time and, more generally, more homogeneity in bank interconnectedness. To illustrate this difference between the core and the periphery, figure A5.1 plots the hypothetical impact of a 1 basis point shock on loans for each value of *IC* in the sample. We plot the response of total loans implied by the estimated models at $t + 6$ to a shock taking place at t both for core and periphery countries. It is clear that, given the respective levels of interconnectedness, a contractionary surprise is more likely to affect the supply of loans in the periphery. We can see that the effects of monetary policy are almost entirely to the left of zero for periphery, but relatively centered for core countries.

It has been noted that the effects of monetary policy may be different during financial crises (Mishkin, 2009). To control for this phenomenon, table A6.3 presents the benchmark model excluding the financial crisis of 2008 and 2009, and the sovereign debt crisis period from September 2008 to December 2013. Both the coefficient for monetary policy and the interaction term are higher in absolute values than in the full sample.

²⁵As a measure for the corporate bond spread we use the Merrill Lynch EMU corporate Index, as suggested by Krylova (2016).

²⁶All variables are in logarithms.

The same holds true for the cutoff value of interconnectedness. This suggests that in absence of a crisis, lending reacts more strongly to changes in the interest rate. A potential explanation to this may be that during the crisis, the demand side plays a more important role in determining the total volume of loans.²⁷ On the supply side, the mechanism might also be affected by liquidity concerns. While the model suggests that lower rates would lead to higher lending during the financial and sovereign debt crisis periods, banks in the euro area were effectively undergoing situations of severe liquidity distress. This might have reduced the effectiveness of the balance sheet channel. It is also worth noting that even though interest rates decreased during this period (which usually raises the value of assets) the crisis was, in reality, accompanied by a decrease in the value of many assets, including real estate). This, in turn, possibly further reduced the volume of loans.

Lastly, we address the two outliers in our sample: Luxembourg and Greece. The former constitutes a financial hub with extremely high bank interconnectedness and the latter underwent unconventional distress during the sampled period. Excluding the two countries from our analysis does not change our results; in fact, the point estimates are almost identical to ones of the benchmark model.²⁸

8 Conclusion

We have explored how the degree of interconnectedness of banks at a country level – as a specific source of *structural heterogeneity* – can lead to different responses to a common monetary policy shock across countries in the euro area. Theory suggests that if the balance sheet transmission channel is at play, an increase in the interest rate reduces the value of pledgeable assets held by firms and households. This reduction in the borrowers' creditworthiness consequently induces banks to constrain the amount of lending. A higher degree of interconnectedness of the banking sector, however, makes banks less sensitive to changes in the value of the collateral posted by borrowers since loan portfolios can be traded among banks with different risk exposures. The significant variation of bank interconnectedness in the euro area – both across time and countries – makes the hypothesis of bank interconnectedness as a determinant of heterogeneous monetary policy effects particularly relevant.

We have tested this hypothesis using local projections and a panel dataset of 12 euro-area countries in the period between 2003 and 2018. We have found strong evidence that interconnectedness constitutes an important driver of heterogeneity in the transmission of monetary policy. In particular, we have shown that when bank interconnectedness is low, contractionary monetary policy leads to a reduction in lending. In countries with highly interconnected banking sectors, however, we have documented that the impact of monetary policy on loans may be offset or even counteracted. These effects hold for both household and corporate loans. Moreover, using our estimates and the observed levels of interconnectedness we illustrate the heterogeneous responses of different countries. A potential conjecture for the observed increase in loans with high bank interconnectedness could be that contractionary shocks induce lending from highly interconnected core countries to countries with low bank interconnectedness. Additionally, higher rates may motivate banks to increase the loan supply due to higher potential returns in a context of efficient risk-sharing. Finally, it is worth mentioning that the effects observed seem to be persistent for approximately 15 months.

Bank interconnectedness differs across countries and over time. Our results suggest that cross-country variation of bank interconnectedness, in particular, plays an important role in explaining heterogeneous responses to monetary policy. Muting the cross-country variation, by contrast, still delivers effects that are in line with the theory but the results are not significant. Furthermore, we find that our results are robust to using alternative shock measures, including additional controls, and excluding outliers.

Nonetheless, our analysis entails a number of caveats that may provide input for further research. The euro area has constantly evolved since 2003 and now consists of 19 countries. Constructing an unbalanced

²⁷Ciccarelli et al. (2015) suggests that the supply side usually drives the outstanding amount of loans.

²⁸See table A6.3.

panel with the countries that have progressively joined the EMU could significantly enhance the power of the analysis by adding more observations. Additionally, our results suggest that when banks are highly interconnected, a contractionary monetary policy shock may increase the volume of loans. Using bank-level data, this effect could be studied in more detail. We could for instance test whether our conjecture for the increase in loans can be supported with empirical evidence. Lastly, our theoretical model is based on the idea that banks alter their loan supply in accordance with the value of assets in the economy to assure that they can safely repay their depositors. Hence, the theory hinges on the fact that banks are financed by deposits. An important extension of the model would be to analyze whether banks with a larger share of non-core liabilities relative to deposits are even more sensitive to changes in the interest rate.

In sum, this analysis contributes to the understanding of how monetary policy is transmitted across countries in the euro area. We have shown how heterogeneous responses can be explained by the countries' individual levels of bank interconnectedness. Furthermore, it provides a potential explanation for why recent research has found rather modest responses of loan supply to monetary policy. This result is expected given that at the average level of bank interconnectedness the reaction of loans to monetary policy is moderate or even nonexistent. Only by incorporating interbank lending into the analysis, sizable effects of monetary policy become apparent.

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Appendix

A Tables and figures

A1 Monetary policy shock

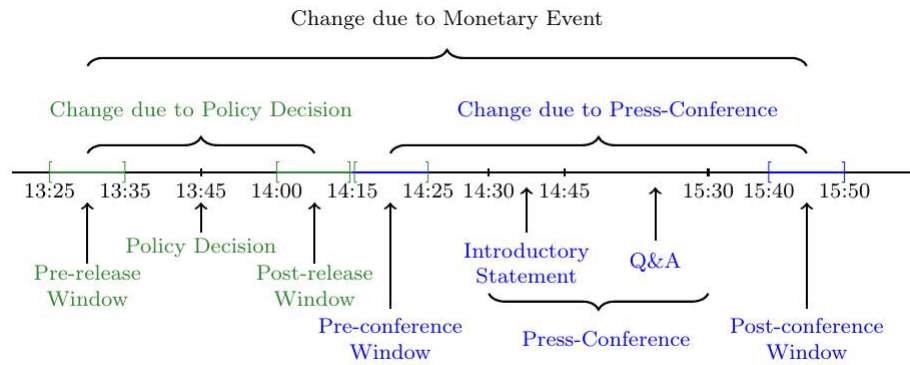


Figure A1.1: ECB policy communication timeline (Altavilla et al., 2019, figure 1, p. 46).

A2 Descriptive statistics by country

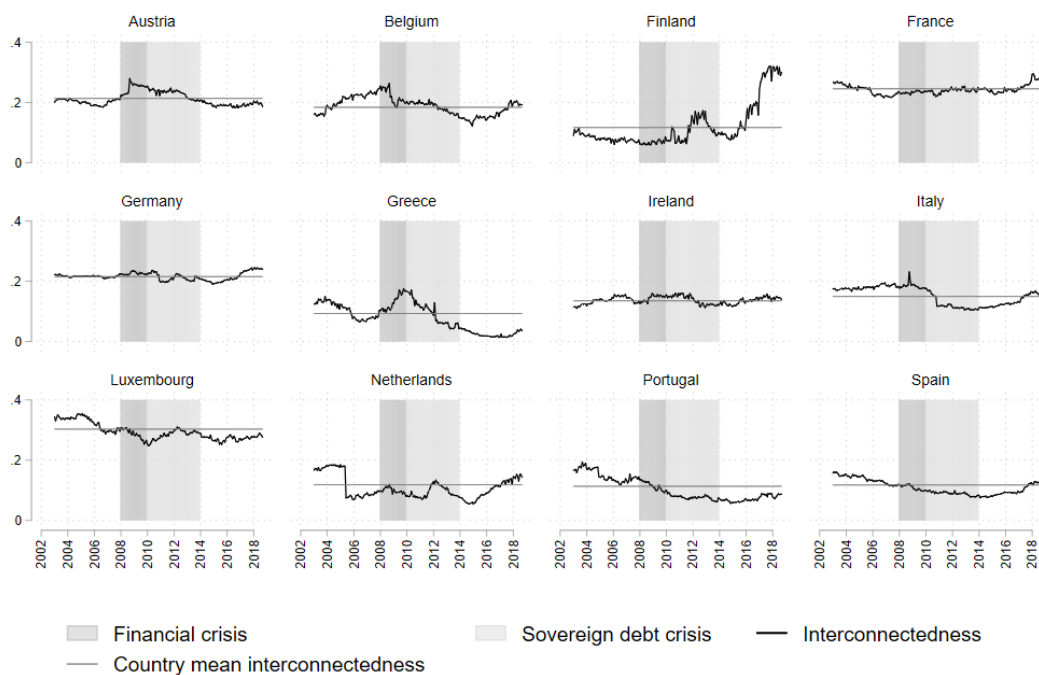


Figure A2.1: Interconnectedness across countries and time

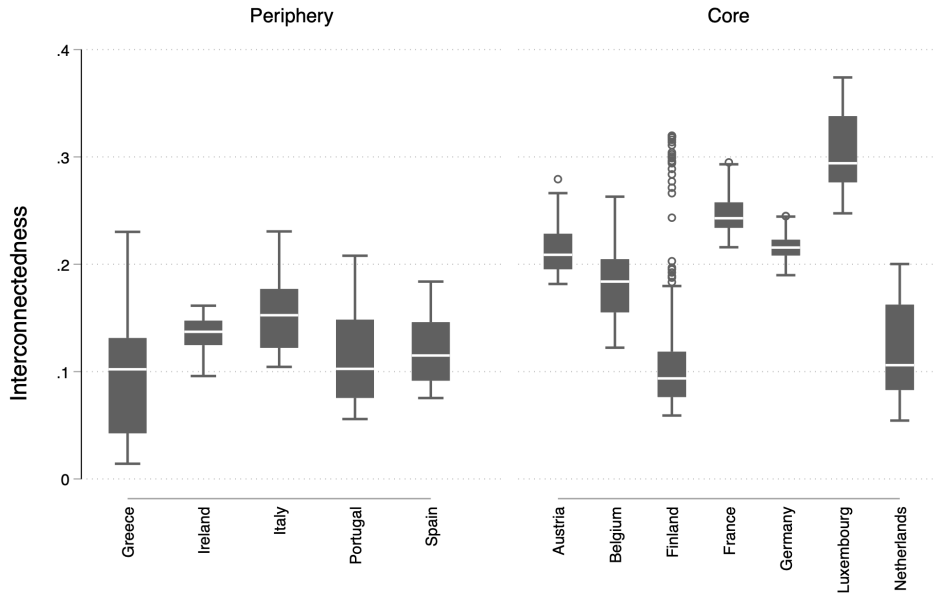


Figure A2.2: Interconnectedness summary statistics

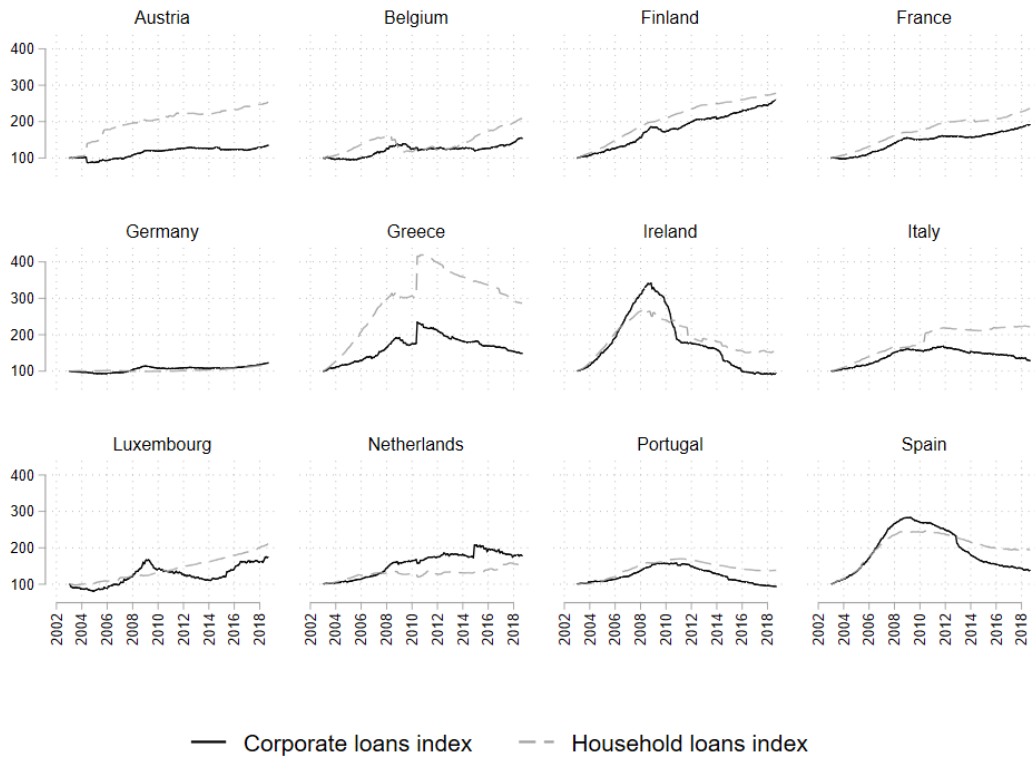


Figure A2.3: Household loans and corporate loans across countries and time

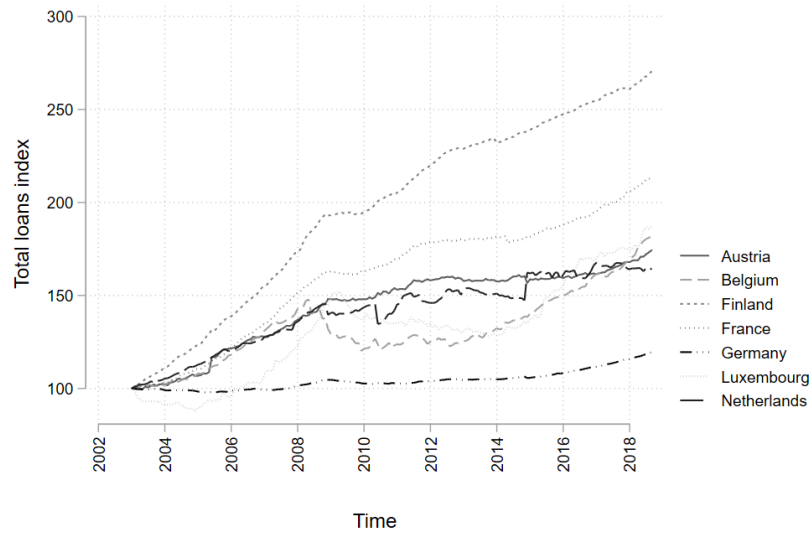


Figure A2.4: Total loans, core countries

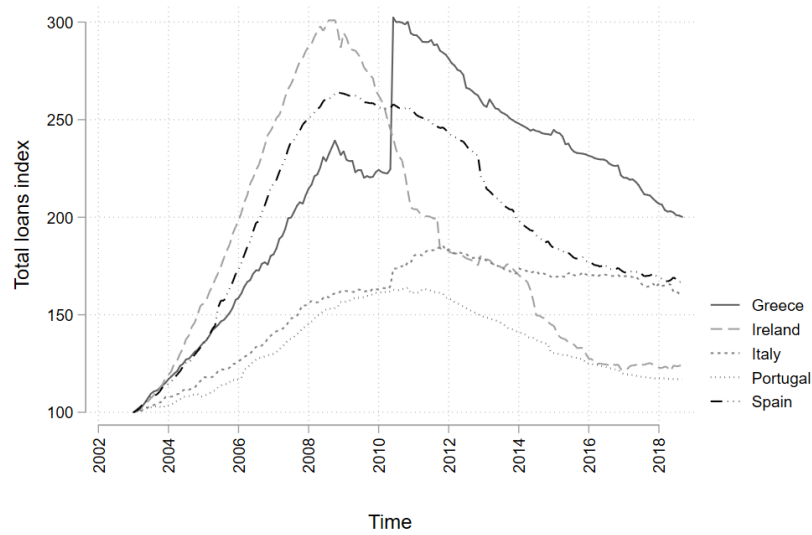


Figure A2.5: Total loans, periphery countries

Table A2.1: Summary statistics: country level interconnectedness, household and corporate loans

Country	Mean interconnectedness	Mean household loans	Mean corporate loans
Austria	0.213	130175	149624
Belgium	0.184	127843	109804
Finland	0.117	97587	59173
France	0.245	950954	800415
Germany	0.216	1466000	884746
Greece	0.093	93886	88187
Ireland	0.135	112589	101531
Italy	0.150	515500	777800
Luxembourg	0.303	32593	52685
Netherlands	0.118	426639	330422
Portugal	0.114	120330	97046
Spain	0.118	726548	668292

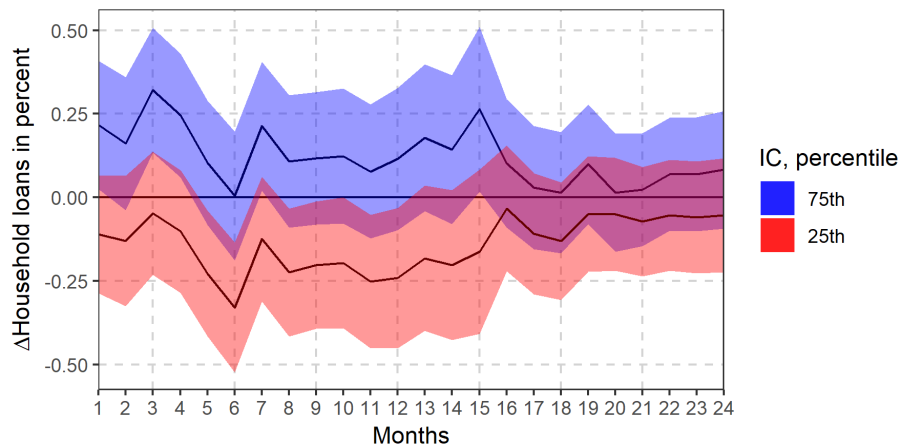
Interconnectedness is computed as the amount of loans among MFIs over the total amount of assets.

Country means are computed as averages of observations within one country across time. Loans in million euros.

A3 Benchmark panel IRFs

Table A3.1: Response to a one basis point monetary policy shock

	1 lag	3 lags	6 lags	9 lags	12 lags	15 lags	18 lags	24 lags
Low IC	-0.050	-0.047	-0.295	-0.158	-0.163	-0.108	-0.159	-0.037
High IC	0.255	0.318	0.045	0.164	0.194	0.287	-0.040	0.094

**Figure A3.1:** Benchmark: IRF of household loans to a one basis point increase in MP_t

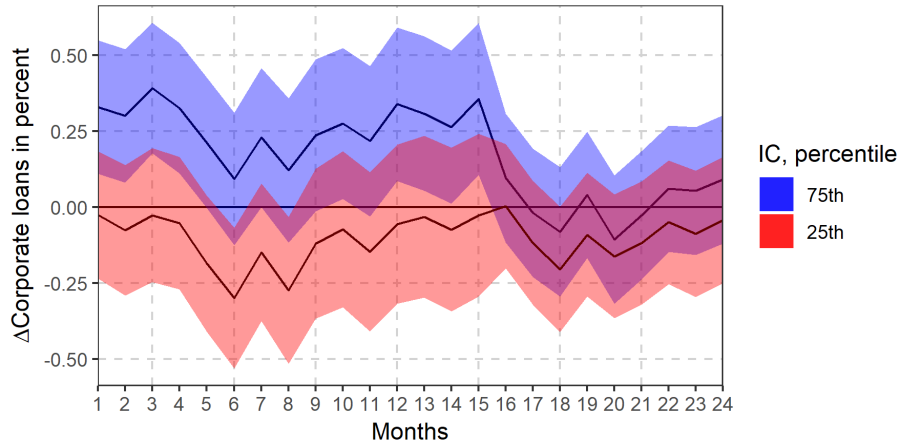


Figure A3.2: Benchmark: IRF of corporate loans to a one basis point increase in MP_t

A4 Cross-country variation of interconnectedness

Table A4.1: Results muting variation over time

	log(total loans)	
MP_{t-3}	-0.615***	(0.236)
IC_{t-3}	-16.574***	(0.295)
$MP_{t-3} \times IC_{t-3}$	4.360***	(1.170)
Fin. distress $_{t-3}$	0.322***	(0.077)
$MP_{t-3} \times \text{Fin. distress}_{t-3}$	-0.295	(0.639)
$\log(\text{GDPpc})_{t-3}$	-0.900***	(0.124)
$MP_{t-3} \times \log(\text{GDPpc})_{t-3}$	-0.914	(1.904)
Trend	0.004***	(0.001)
$MP_{t-3} \times \text{Trend}$	0.002	(0.002)
Adj. R-squared	0.987	
Observations	2268	
Country FE	Yes	
Month FE	Yes	
Year FE	Yes	

Newey-West SE in parentheses; * $p < .10$, ** $p < .05$, *** $p < .01$

Shock in percentage points; Mean IC = 0.167

All explanatory variables except for MP and IC are demeaned

A5 Heterogeneous responses to shocks

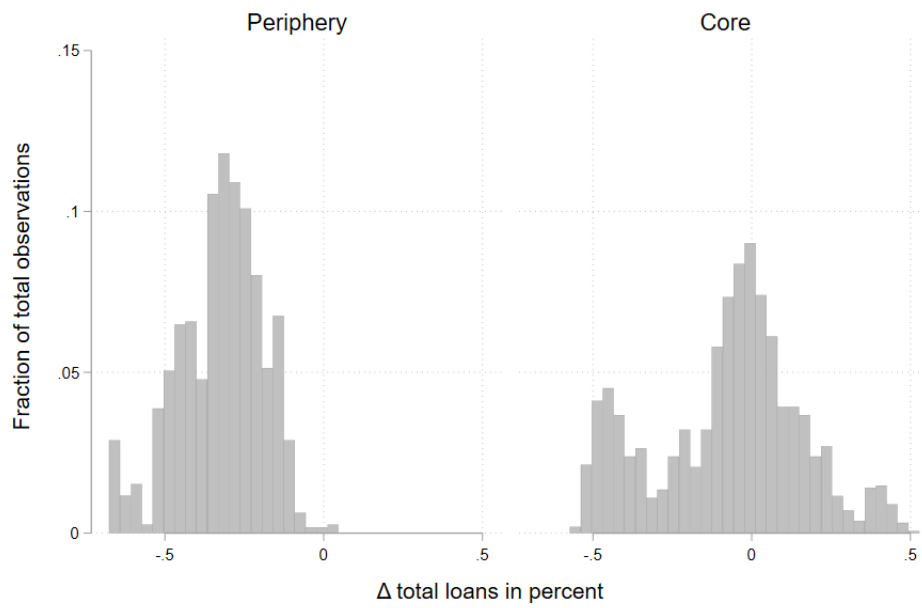


Figure A5.1: Response after 6 months to a 1 basis point shock based on the empirical distribution of *IC* by core and periphery

A6 Robustness checks

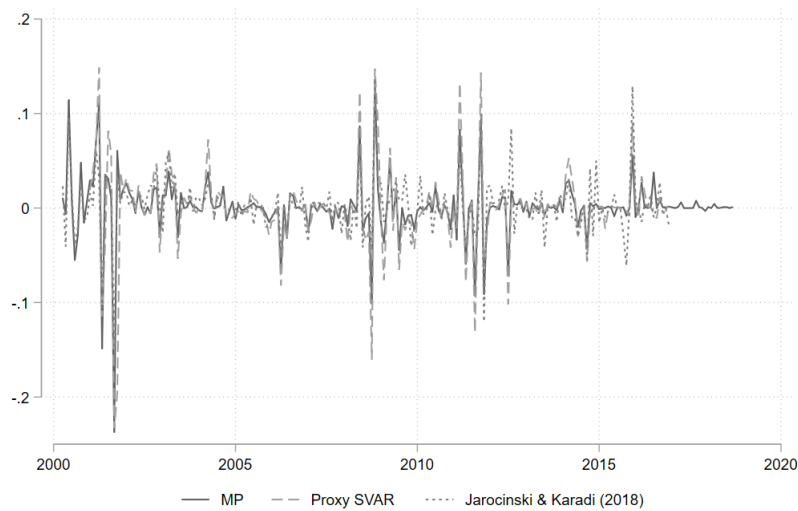


Figure A6.1: Comparison of MP shock measures

Table A6.1: Robustness checks: alternative MP shock measures

	Proxy SVAR		Jarociński and Karadi (2018)	
MP_{t-3}	-0.271*	(0.150)	-0.283	(0.207)
IC_{t-3}	0.888***	(0.200)	0.881***	(0.200)
$MP_{t-3} \times IC_{t-3}$	2.462***	(0.717)	1.773*	(1.013)
Fin. distress $_{t-3}$	0.297***	(0.075)	0.297***	(0.075)
$MP_{t-3} \times$ Fin. distress $_{t-3}$	-0.432	(0.449)	0.230	(0.770)
$\log(\text{GDPpc})_{t-3}$	-0.967***	(0.134)	-0.964***	(0.134)
$MP_{t-3} \times \log(\text{GDPpc})_{t-3}$	-0.990	(1.350)	-0.015	(1.668)
Trend	0.004***	(0.001)	0.004***	(0.001)
$MP_{t-3} \times$ Trend	0.002	(0.002)	0.001	(0.002)
Adj. R-squared	0.989		0.989	
Observations	2052		2052	
Country FE	Yes		Yes	
Month FE	Yes		Yes	
Year FE	Yes		Yes	

Newey-West SE in parentheses; * $p < .10$, ** $p < .05$, *** $p < .01$

Shock in percentage points; Mean IC = 0.167

All explanatory variables except for MP and IC are demeaned

Table A6.2: Specifications with additional controls

	log(total)	log(total)	log(total)	log(CL)	log(HHL)
MP _{t-3}	-0.475** (0.204)	-0.583*** (0.202)	-0.632*** (0.202)	-0.674*** (0.235)	-0.589*** (0.228)
IC _{t-3}	1.121*** (0.143)	0.477*** (0.131)	0.467*** (0.138)	0.660*** (0.190)	0.421*** (0.160)
MP _{t-3} × IC _{t-3}	3.734*** (0.985)	3.898*** (1.016)	4.005*** (1.016)	4.390*** (1.146)	3.626*** (1.138)
Fin. distress	0.284*** (0.076)	0.207*** (0.058)	0.191*** (0.058)	0.138* (0.079)	0.247*** (0.064)
MP _{t-3} × Fin. distress _{t-3}	-0.482 (0.629)	-1.092* (0.611)	-1.267** (0.621)	-1.912** (0.757)	-0.513 (0.709)
log(GDPpc) _{t-3}	-1.060*** (0.110)	-0.659*** (0.129)	-0.566*** (0.120)	-0.652*** (0.174)	-0.592*** (0.117)
MP _{t-3} × log(GDPpc) _{t-3}	-1.503 (1.851)	0.148 (1.761)	-0.479 (1.803)	-1.545 (2.324)	0.584 (2.110)
log(banks' assets) _{t-3}		0.143** (0.059)	0.259*** (0.055)	0.231*** (0.067)	0.266*** (0.059)
MP _{t-3} × log(banks' assets) _{t-3}		0.607 (0.642)	1.035 (0.636)	0.881 (0.732)	1.283* (0.726)
Leverage _{t-3}		0.015*** (0.002)	0.013*** (0.002)	0.016*** (0.003)	0.009*** (0.002)
MP _{t-3} × Leverage _{t-3}		0.036 (0.030)	0.028 (0.033)	0.075* (0.043)	-0.036 (0.039)
log(banks' size) _{t-3}		0.063*** (0.016)	0.076*** (0.016)	0.119*** (0.022)	0.050*** (0.014)
MP _{t-3} × log(banks' size) _{t-3}		-0.577* (0.323)	-0.487 (0.329)	-0.489 (0.454)	-0.457 (0.291)
Trade int. _{t-3}			0.209*** (0.043)	0.249*** (0.053)	0.182*** (0.045)
MP _{t-3} × Trade int. _{t-3}			0.614 (0.814)	1.023 (0.922)	-0.031 (0.991)
Trend	0.004*** (0.001)	0.003*** (0.001)	0.003*** (0.001)	0.001* (0.001)	0.004*** (0.001)
MP _{t-3} × Trend	0.002 (0.002)	0.005* (0.003)	0.003 (0.004)	0.004 (0.004)	0.002 (0.004)
Adj. R-squared	0.988	0.991	0.992	0.986	0.991
Observations	2268	2268	2268	2268	2268
Country FE	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes

Newey-West SE in parentheses; * p<.10, ** p<.05, *** p<.01

Shock in percentage points; Mean IC = 0.167

All explanatory variables except for *MP* and *IC* are demeaned

Table A6.3: Sub-samples of the panel

	No crisis log(total)		No Lux. log(total)		No Lux./Greece log(total)	
MP_{t-3}	-2.912***	(0.607)	-0.419**	(0.212)	-0.408*	(0.241)
IC_{t-3}	1.475***	(0.164)	1.277***	(0.142)	1.096***	(0.147)
$MP_{t-3} \times IC_{t-3}$	16.652***	(3.253)	3.814***	(1.140)	3.726***	(1.249)
Trend	0.006***	(0.001)	0.004***	(0.001)	0.004***	(0.001)
$MP_{t-3} \times$ Trend	0.006*	(0.003)	0.002	(0.003)	0.002	(0.003)
Fin. distress	0.162	(0.129)	0.301***	(0.078)	0.255***	(0.086)
$MP_{t-3} \times$ Fin. distress $_{t-3}$	-6.881*	(3.866)	-0.690	(0.675)	-0.927	(0.692)
$\log(\text{GDPpc})_{t-3}$	-1.293***	(0.148)	-1.052***	(0.102)	-1.289***	(0.120)
$MP_{t-3} \times \log(\text{GDPpc})_{t-3}$	-11.672***	(3.986)	-1.704	(1.866)	-2.039	(2.551)
Adj. R-squared	0.988		0.986		0.986	
Observations	1356		2079		1890	
Country FE	Yes		Yes		Yes	
Month FE	Yes		Yes		Yes	
Year FE	Yes		Yes		Yes	

Newey-West SE in parentheses; * p<.10, ** p<.05, *** p<.01

Shock in percentage points; Mean IC = 0.167

All explanatory variables except for MP and IC are demeaned

Table A6.4: Regression for core and periphery

	Core log(total)		Periphery log(total)	
MP_{t-3}	-0.154	(0.267)	-0.590	(0.410)
IC_{t-3}	0.347***	(0.103)	-0.260	(0.393)
$MP_{t-3} \times IC_{t-3}$	1.186	(1.099)	6.823*	(3.486)
Fin. distress	0.146***	(0.055)	0.181**	(0.081)
$MP_{t-3} \times$ Fin. distress $_{t-3}$	0.186	(0.470)	-1.429	(0.923)
$\log(\text{GDPpc})_{t-3}$	-2.053***	(0.229)	-1.056***	(0.091)
$MP_{t-3} \times \log(\text{GDPpc})_{t-3}$	-0.653	(3.638)	-0.572	(1.620)
Trend	0.004***	(0.001)	0.003**	(0.001)
$MP_{t-3} \times$ Trend	0.001	(0.002)	0.005	(0.004)
Adj. R-squared	0.996		0.989	
Observations	1323		945	
Country FE	Yes		Yes	
Month FE	Yes		Yes	
Year FE	Yes		Yes	

Newey-West SE in parentheses; * p<.10 ** p<.05 *** p<.01

Shock in percentage points; Mean IC = 0.167

All explanatory variables except for MP and IC are demeaned

B Data sources

Table A0.1: Data sources

Data	Freq.	Level	Construction	Source
Loans vis-a-vis euro area households reported by MFI excluding ESCB in the euro area (stock)	Monthly	Country + EU19		ECB SDW
Loans vis-a-vis euro area non-financial reported by MFI excluding ESCB in the euro area (stock)	Monthly	Country + EU19		ECB SDW
Industrial Production (excl. construction)	Monthly	Country		ECB SDW
CLIFS - Country-Level Index of Financial Stress	Monthly	Country		ECB SDW
CISS - Composite Indicator of Systemic Stress	Monthly	EU19		ECB SDW
Loans vis-a-vis euro area MFI reported by MFI excluding ESCB in the euro area (stock)	Monthly	Country + EU19		ECB SDW
Total Assets/Liabilities reported by MFI excluding ESCB/GDP	Monthly	Country + EU19		ECB SDW
Harmonised Index of Consumer Prices	Monthly	EU 19		Eurostat
Merrill Lynch EMU Corporate Bond Index	Monthly			TR Eikon
Exports/GDP	Monthly	Country + EU19		OECD
Imports/GDP	Monthly	Country + EU19		OECD
Gross domestic product at market prices	Quarterly	Country + EU19	Transformed into monthly by repeating thrice each quarterly figure.	Eurostat
Gross domestic product per capita at constant prices	Quarterly	Country	Transformed into monthly by repeating thrice each quarterly figure.	OECD
Total number of Credit Institutions	Yearly	Country		ECB SDW
Capital and reserves	Monthly	Country		ECB SDW
Germany 2Y Bond Yield	Daily		Daily change around ECB's policy announcement window. Monthly measure = sum across months.	Altavilla et al. (2019)
3M swaps Euro OverNight Index Average (Eonia)	Daily		Daily change around ECB's policy announcement window. Monthly measure = sum across months.	Altavilla et al. (2019)
Monetary Policy shock measure by Jarocinski and Karadi (2018)	Daily		Days without shock set to 0. Monthly measure = monthly average.	Jarocinski and Karadi (2018)

C Complete theoretical model

Setup²⁹:

- 2 Periods ($t = 0, 1$)
- 3 agents: Savers, Entrepreneurs, Banks
- Timing
 - $t = 0$ Savers deposit money in banks, banks lend to entrepreneurs, entrepreneurs make investment decision (risky vs. safe project)
 - $t = 1$ Entrepreneurs repay their loan or have their collateral A , banks repay savers

The expected profit of the entrepreneur investing in the risky project is given by:

$$0.5[R - (1 + r)]I_r - 0.5A$$

where R is the return to investment ($R > 2$), r is interest rate charged to borrowers, A is the value of the collateral posted by the borrowers and I_r is the amount invested in the risky project. It is further assumed that $0.5(R - A) > 1$. The probability of success is set to 0.5.

The full maximization problem of the entrepreneur is defined as

$$\begin{aligned} \max_{I_s, I_r} \{ & 0.5[R - (1 + r)]I_r \} - 0.5\chi(I_r > 0) + I_s(0 - r) \\ \text{s.t. } & I_s + I_r = I \\ & r = r(I) \end{aligned}$$

where I_r is the amount invested in the risky project and I_s is the amount invested in the safe project. χ is an indicator function that takes the value 1 as soon as $I_r > 0$.

The bank's maximization problem is given by

$$\begin{aligned} \max_{I, m} E_s [& (1 + r(I, s))I] + m - 1 - r_d \\ \text{s.t. } & I + m = 1 \\ & (1 + r(I, s))I + m \geq 1 + r_d \end{aligned}$$

where m is money and r_d is the interest rate paid to savers. The second condition states that banks allocate deposits between loans and money. The third condition states that the bank's revenues from lending paired with the money reserves of the bank must be sufficient to pay back the savers.

Credit rationing occurs as banks incentivize borrowers to invest in the safe project. Borrowers prefer the safe over the risky project if the expected return from the risky project is smaller or equal to their outside option of earning an excess return of 0 by investing in the safe project.

$$0.5[R - (1 + r(I))]I_r + 0.5(0 - A) \leq 0$$

Banks hence set available credit according to

$$\Rightarrow I_r \leq \frac{A}{R - (1 + r(I))}$$

²⁹The model is taken from Barattieri et al. (2018). While their study analyzes the US, the argument is directly applicable to the euro area – which is why we have not made any attempts at modifying the model.

Banks end up setting $r_d = 0$ and charge borrowers an interest rate of $r(I) = 0$. If all entrepreneurs implement the safe project, this allows the banks to simply collect the money from entrepreneurs and transfer it back to savers.

In this setting, bank lending is sensitive to the value of the collateral available in the economy

$$\frac{\partial I}{\partial A} = \frac{1}{R-1}$$

In a situation in which inter-bank lending is possible, the banks' maximization problem becomes

$$\begin{aligned} \max_{I, m, I^{sec}, I^d} E_s [(1 + r(I, s)) (I - I^{sec})] + m + pI^{sec} - pI^d + \int_0^1 (1 + r(s))I^d ds - 1 - r_d \\ I + m = 1 \\ (1 + r(I, s)) (I - I^{sec}) + m + pI^{sec} - pI^d + \int_0^1 (1 + r(s))I^d ds \geq 1 + r_d \end{aligned}$$

where I^{sec} denotes securitized loans in the bank's portfolio that are being sold in the interbank market and I^d denotes loans from other banks' portfolios that are being purchased in the interbank market. The conditions of the problem stay essentially the same as before. The bank's revenues, which come now from lending, storing money and trading with other banks, must still be sufficiently large so as to be able to pay back depositors.

Banks eventually end up selling their entire portfolio ($I^{sec} = I$) and buying a fully diversified portfolio in the interbank market ($I^d = I$). In this specific setting, banks no longer need to make sure that entrepreneurs implement the safe project. That is banks no longer need to ration credit, i.e. $I = 1 = I_r$. In this setting, all entrepreneurs implement the risky project. This leads to

$$0.5[R - (1 + r)] + 0.5(0 - A) = 0 \Rightarrow 1 + r = R - A$$

The banks profits are then given by

$$0.5(1 + r) - 1 - r_d = 0.5(R - A) - 1 - r_d$$

Given competition between banks the zero profit condition must hold:

$$0.5(R - A) - 1 - r_d = 0$$

The zero profit condition thus implicitly defines the interest rate paid to depositors. r_d is positive given the assumption that $0.5(R - A) > 1$. Interbank lending allows banks to make positive profits which they redistribute to savers by paying them a higher interest rate.

The sensitivity of lending with respect to the value of the collateral is eventually reduced to:

$$\frac{\partial I}{\partial A} = 0$$

Considering that only a fraction of banks may be potentially be interconnected, the overall sensitivity of lending becomes

$$\frac{\partial I}{\partial A} = (1 - \lambda) \frac{1}{R-1} + \lambda \cdot 0$$

which is increasing in the fraction of banks that trade with each other in the interbank market.

$$\frac{\partial^2 I}{\partial \lambda \partial A} = -\frac{1}{R-1} < 0$$

D Marginal effects and confidence bands

The marginal effect of a monetary policy surprise is complicated somewhat by our inclusion of interaction terms. We are interested in how different levels of interconnectedness affect this marginal effect. Hence, we compute two marginal effects for each horizon: One for interconnectedness set at the value of the first quartile (25) and one set at the third quartile (75). All controls are demeaned and, thus, do not matter for the marginal effect when evaluated at their means. Formally, we have a marginal effect of MP at horizon h given by:

$$ME^{(h)} = \frac{\partial y_{i,t+h}}{\partial MP_t} = \begin{cases} \beta_{MP_t}^{(h)} + \beta_{MP_t \times IC_t}^{(h)} IC_{75} \equiv g_{75}^{(h)} \\ \beta_{MP_t}^{(h)} + \beta_{MP_t \times IC_t}^{(h)} IC_{25} \equiv g_{25}^{(h)} \end{cases}$$

The marginal effects are computed for $h = 1, 2, \dots, H$. This means that the two paths for the resulting impulse response functions need not be parallel over the horizon. To compute the marginal effects, we rely on numerical derivatives, i.e. numeric approximations of the partial derivatives. Consequently, the variances of the marginal effects require some numerical approximation (Leeper, 2018). Specifically, we follow the delta method and compute the variance-covariance matrix of a marginal effect at horizon h as:

$$\mathbb{V}ME^{(h)} = J \times \mathbb{V}\hat{\beta}^{(h)} \times J^\top$$

where J is the Jacobian matrix and $\mathbb{V}\hat{\beta}^{(h)}$ is the variance-covariance matrix of the coefficients from the regression, estimated by $\mathbb{V}\hat{\beta}^{(h)}$. The Jacobian consists of partial derivatives with respect to the regression coefficients and does not change with h . In our case, the Jacobian is the $2 \times (k+2)$ matrix³⁰

$$J = \begin{pmatrix} \frac{\partial g_{75}^{(h)}}{\partial \beta_{MP_t}^{(h)}} & \frac{\partial g_{75}^{(h)}}{\partial \beta_{MP_t \times IC_t, 75}^{(h)}} & \frac{\partial g_{75}^{(h)}}{\partial \beta_{MP_t \times X_1}^{(h)}} & \dots & \frac{\partial g_{75}^{(h)}}{\partial \beta_{MP_t \times X_k}^{(h)}} \\ \frac{\partial g_{25}^{(h)}}{\partial \beta_{MP_t}^{(h)}} & \frac{\partial g_{25}^{(h)}}{\partial \beta_{MP_t \times IC_t, 25}^{(h)}} & \frac{\partial g_{25}^{(h)}}{\partial \beta_{MP_t \times X_1}^{(h)}} & \dots & \frac{\partial g_{25}^{(h)}}{\partial \beta_{MP_t \times X_k}^{(h)}} \end{pmatrix} = \begin{pmatrix} 1 & IC_{75} & 0 & \dots & 0 \\ 1 & IC_{25} & 0 & \dots & 0 \end{pmatrix}$$

and the $(k+2) \times (k+2)$ variance-covariance matrix of the regression coefficients is

$$\mathbb{V}\hat{\beta}^{(h)} = \begin{pmatrix} \mathbb{V}\hat{\beta}_{MP_t}^{(h)} & \gamma_{MP_t, IC_t}^{(h)} & \gamma_{MP_t, X_1}^{(h)} & \gamma_{MP_t, X_2}^{(h)} & \dots & \gamma_{MP_t \times X_k}^{(h)} \\ \gamma_{MP_t, IC_t}^{(h)} & \mathbb{V}\hat{\beta}_{MP_t \times IC_t}^{(h)} & \gamma_{MP_t \times IC_t, X_1}^{(h)} & \gamma_{MP_t \times IC_t, X_2}^{(h)} & \dots & \gamma_{MP_t \times IC_t, X_k}^{(h)} \\ \gamma_{MP_t, X_1}^{(h)} & \gamma_{MP_t \times IC_t, X_1}^{(h)} & \mathbb{V}\hat{\beta}_{MP_t \times X_1}^{(h)} & \gamma_{MP_t \times X_1, X_2}^{(h)} & \dots & \gamma_{MP_t \times X_1, X_k}^{(h)} \\ \gamma_{MP_t, X_2}^{(h)} & \gamma_{MP_t \times IC_t, X_2}^{(h)} & \gamma_{MP_t \times X_1, X_2}^{(h)} & \ddots & \ddots & \vdots \\ \vdots & \vdots & \vdots & \ddots & \ddots & \vdots \\ \gamma_{MP_t \times X_k}^{(h)} & \gamma_{MP_t \times IC_t, X_k}^{(h)} & \gamma_{MP_t \times X_1, X_k}^{(h)} & \dots & \gamma_{MP_t \times X_1, X_{k-1}}^{(h)} & \mathbb{V}\hat{\beta}_{MP_t \times X_k}^{(h)} \end{pmatrix}$$

³⁰ k is the number of control variables included in the model.

where $\gamma_{A,B}^{(h)} \equiv Cov(\hat{\beta}_A^{(h)}, \hat{\beta}_{A \times B}^{(h)})$. Pre-multiplying with J and post-multiplying with J^\top yields the 2×2 variance-covariance matrix of the marginal effect at h

$$\mathbb{V}ME^{(h)} = \begin{pmatrix} \mathbb{V}ME_{75}^{(h)} & \gamma_{75,25}^{(h)} \\ \gamma_{75,25}^{(h)} & \mathbb{V}ME_{25}^{(h)} \end{pmatrix}$$

where $\gamma_{75,25}^{(h)}$ is the covariance between the marginal effects and $\mathbb{V}ME_p^{(h)}$ is the variance of the marginal effect of MP evaluated at interconnectedness at the p^{th} percentile. We use the standard errors, $\sigma_{ME_p^{(h)}} = \sqrt{\mathbb{V}ME_p^{(h)}}$, to compute confidence bands around our marginal effects in our impulse response functions. To see how this methodology can yield different confidence bands for different levels of interconnectedness, consider the following:

$$\left(J \times \mathbb{V}\hat{\beta}^{(h)} \right)_p^\top = \begin{pmatrix} \mathbb{V}\hat{\beta}_{MP_t}^{(h)} + IC_p \gamma_{MP_t, IC_t}^{(h)} \\ \gamma_{MP_t, IC_t}^{(h)} + IC_p \mathbb{V}\hat{\beta}_{MP_t \times IC_t}^{(h)} \\ 0 \\ \vdots \\ 0 \end{pmatrix}$$

is one of the two rows of the $2 \times (k+2)$ matrix $J \times \mathbb{V}\hat{\beta}^{(h)}$.

Post-multiplying $J \times \mathbb{V}\hat{\beta}^{(h)}$ by J^\top yields the 2×2 variance-covariance matrix of the marginal effects in which the diagonal elements used for construction of confidence bands are given by:

$$\begin{aligned} \mathbb{V}ME_p^{(h)} &= \mathbb{V}\hat{\beta}_{MP_t}^{(h)} + IC_p \gamma_{MP_t, IC_t}^{(h)} + IC_p \left(\gamma_{MP_t, IC_t}^{(h)} + IC_p \mathbb{V}\hat{\beta}_{MP_t \times IC_t}^{(h)} \right) \\ &= \mathbb{V}\hat{\beta}_{MP_t}^{(h)} + IC_p \left(\gamma_{MP_t, IC_t}^{(h)} + \gamma_{MP_t, IC_t}^{(h)} \right) + IC_p^2 \mathbb{V}\hat{\beta}_{MP_t \times IC_t}^{(h)} \end{aligned}$$

The confidence bands of the marginal effect at the 75th percentile is larger than at the 25th percentile if

$$\begin{aligned} &\mathbb{V}ME_{75}^{(h)} > \mathbb{V}ME_{25}^{(h)} \\ \Leftrightarrow &(IC_{75} - IC_{25}) \left(\gamma_{MP_t, IC_t}^{(h)} + \gamma_{MP_t, IC_t}^{(h)} \right) + (IC_{75}^2 - IC_{25}^2) \mathbb{V}\hat{\beta}_{MP_t \times IC_t}^{(h)} > 0 \end{aligned}$$

where $IC_{75} - IC_{25} > 0$, $IC_{75}^2 - IC_{25}^2 > 0$, $\mathbb{V}\hat{\beta}_{MP_t \times IC_t}^{(h)} > 0$, and $\gamma_{MP_t, IC_t}^{(h)} + \gamma_{MP_t, IC_t}^{(h)} \gtrless 0$. Hence, depending on the relative size of the terms, the paths of the marginal effects need not be parallel and, furthermore, the confidence bands can be dissimilar and change markedly over the projection horizon.