

Systemic Bank Risk and Monetary Policy*

Ester Faia^a and Sören Karau^b

^aGoethe University Frankfurt and CEPR

^bDeutsche Bundesbank

The risk-taking channel of monetary policy acquires relevance for macro policymakers only if it affects systemic risk. We find robust evidence that a monetary tightening lowers systemic risk using cross-country and time-series data in a VAR framework for 29 G-SIBs from seven countries, different risk metrics (ΔCoVaR , LRMES), as well as econometric specifications and identification schemes (panel VAR with recursive identification; proxy VARs using external instruments). We then assess implications for policy. First, we find that both U.S. and euro-area monetary policy shocks spill into other countries' systemic risk. Second, we document that macroprudential policy plays a significant role in taming the unintended consequences of monetary policy on systemic risk, particularly so for U.S. policy spillovers.

JEL Codes: E44, E52, G18, G21.

1. Introduction

Extensive and robust micro evidence exists for the risk-taking channel of monetary policy, namely the notion that the stance of

*We thank discussants and participants at various conferences and seminars. We also thank Refet Gürkaynak and Carlo Altavilla for sharing their data on monetary policy surprises data with us and the research staff of New York University's Volatility Lab for providing us with market capitalization and LRMES data. We gratefully acknowledge financial support from DFG grant FA 1022/1-2. The views expressed in this paper are those of the authors and do not necessarily reflect the views of the Deutsche Bundesbank or the Eurosystem. Corresponding author: Ester Faia, Chair in Monetary and Fiscal Policy, Goethe University Frankfurt, Theodor W. Adorno Platz 3, 60323, Frankfurt am Main, Germany. E-mail: faia@wiwi.uni-frankfurt.de. Webpage: <http://www.wiwi.uni-frankfurt.de/profs/faia/>.

monetary policy affects risk-taking behavior of banks.¹ Based on that, monetary policy faces a tradeoff between the beneficial effects of expansionary policies and the unintended increase in bank risk. So far, micro evidence employed individual bank risk or balance sheet measures (for instance, Altunbas, Gambacorta, and Marques-Ibanez 2014; Jiménez et al. 2014; Ioannidou, Ongena, and Peydró 2015; Dell’Ariccia, Laeven, and Suarez 2017). The effects found therein are robust and significant, but quantitatively too small to be relevant from the perspective of macro policymakers. Furthermore, no evidence exists on systemic effects and on aggregate spillovers.² If effects are limited to individual bank risk, though important, they can be mitigated through microprudential regulation. In this paper we examine the impact of monetary policy on systemic risk. Given the existence of such an effect, we then analyze how this can be mitigated through a policy mix. Specifically, we assess monetary policy spillovers across different countries and study complementarities between macroprudential and monetary tools.

We assess the dynamic effects of structural monetary policy shocks on systemic bank risk measures with various VAR specifications. Our data set comprises monthly observations for 29 global systemically important banks (G-SIBs) headquartered in seven economies. The effect of monetary policy on bank risk can extend to systemwide risk through two channels, namely network connections and pecuniary externalities. In the first case, an increase in leverage brings about an increase in banks’ interconnectedness in wholesale repo or CDS markets. Cascading failures then emerge in response to idiosyncratic shocks.³ In the second case, banks, in search for yield collectively, invest in the same set of risky assets, implicitly raising the probability of a systemic crisis if shocks hit those assets.⁴ In order to capture those various dimensions, and also to make sure that our results are not driven by specific measures, we employ two systemic risk metrics. ΔCoVaR measures the codependency of the financial

¹See Borio and Zhu (2008) for the first explicit discussion of the channel. We survey the literature in section 2.

²See Bernanke (2009).

³See Caballero and Simsek (2013) or Greenwood, Landier, and Thesmar (2015) for models of financial networks.

⁴See Allen and Gale (2000) for an early formalization of this channel.

system on a particular bank's value at risk.⁵ Intuitively it measures *contagion* through network connections, as it captures each institution's capacity to spread unfavorable outcomes to the rest of the system. We compute this metric using equity prices as well as CDS spreads. The latter have become known for their higher forecasting power. Our second metric, long-run marginal expected shortfall (LRMES), instead measures how much bank equity would be lost in the event of a systemic downturn, i.e., it measures an institution's systemic *exposure*.⁶ It therefore captures best the consequences of fire-sale externalities in an environment with widespread risky asset commonality.

We exploit both the time-series and the cross-country dimension of our data to ensure that our results are not driven by a particular subsample or country. We estimate an international panel VAR and two proxy VARs for the United States and the euro area. The panel model allows us to study the effect of monetary policy on systemic risk in a multicountry framework which also embeds banks' cross-sectional heterogeneity. The proxy VAR allows us to verify our results under alternative and recently developed instrumental-variable techniques for shock identification. In there we use high-frequency market surprises around monetary policy announcements to isolate exogenous movements in policy.⁷ In order to ensure the most accurate identification of monetary shocks, we purge these market responses from potential confounding factors, such as information effects.⁸

Our analysis is structured in three parts, in each of which we employ both our empirical frameworks. In the first part we establish that across all our specifications an exogenous tightening of monetary policy lowers all three metrics of systemic risk. The effects are robust and sizable also compared with those found in the microeconomic literature. We also make sure that our results are not solely predicated on the occurrence of the financial crisis.

⁵See Adrian and Brunnermeier (2016).

⁶See Brownlees and Engle (2017).

⁷See Gertler and Karadi (2015).

⁸See Nakamura and Steinsson (2018) and Jarocinski and Karadi (2020).

Given these findings, we embark into checking which policy mix would dampen the systemic risk response. We explore monetary policy spillovers across countries and study complementarities between prudential and monetary tools. First, we quantify how much of the effect of monetary policy on systemic risk is driven by national as opposed to U.S. monetary policy. This is against the background that Federal Reserve policy, partly due to the U.S. dollar's dominant international role, is frequently implicated with affecting global monetary and financial conditions (Rey 2015). To answer these questions, we again employ both our empirical models. First, we extract the country-specific structural monetary shocks from our panel VAR. In order to then compare effects of domestic with U.S. shocks, we derive impulse responses in a local projections framework. Second, we add risk measures of a variety of countries to both our U.S. and euro-area proxy VARs and again compare impulse responses. Our findings indicate that it is not only U.S. but also euro-area, next to domestic, monetary shocks that influence systemic bank risk in various countries. Hence spillovers exist, but they are not clearly asymmetric, nor are they predicated on the dominant international role of a currency. This seems reasonable given that the U.S. dollar has a dominant role, particularly for banks' liquidity and international deposits, mainly in countries with unstable inflation rates and weak currencies.⁹ Our sample instead comprises industrialized countries whose banking systems to a larger extent rely on local currency.

At last, we examine whether the unintended consequences of monetary policy on risk can be mitigated through macroprudential policy. To this purpose we use time-series data on macroprudential regulation provided in Alam et al. (2019). First, we compute impulse responses in an interacted panel VAR in "easy" and "tight" macroprudential regimes. We find that the spillovers of monetary shocks to our marginal shortfall measure are significantly dampened, while responses of our ΔCoVaR metrics are not altered much. In a second step, we investigate the marginal effects of macroprudential actions on the monetary transmission in a panel local projections framework. To that end, we extract structural shocks from our panel as well as

⁹See European Central Bank (2019).

the proxy VAR models and compute impulse responses of macroprudential interaction terms. For U.S. shocks we find that all three risk measures are significantly less affected following a tightening of macroprudential regulation. For the euro area and the other countries we find that the dampening effect of macroprudential policy holds mainly for the LRMES measure. Overall, our findings confirm the dampening role of prudential policies in the transmission of monetary shocks.

The policy implications of our analysis can be far reaching. Among other things, they imply that monitoring systemic risk metrics can be part of the policy toolkit alongside with other economic variables. Our findings suggest that this might be particularly valuable for macroprudential policymakers. Further, our results show that global banks contribute to systemic risk in other countries following monetary shocks, which provides evidence of financial spillovers. Through this channel, monetary policy actions in one country, by affecting risk, also spill over to other countries, calling for policy coordination.

The paper is structured as follows. Section 2 reviews the literature. Section 3 presents the main results. Section 4 extends the benchmark specifications to examine the role of cross-country policy spillovers. Section 5 analyzes the policy complementarities of monetary and macroprudential tools. Section 6 concludes.

2. Literature Review

The risk-taking channel of monetary policy was discussed in early contributions by Rajan (2005) and in Borio and Zhu (2008). The theoretical literature examined the risk-taking channel on the liability side and on the asset side of banks' balance sheets. Angeloni and Faia (2013), using a dynamic general equilibrium model with fundamental bank runs, show that banks increase their leverage when policy rates are lowered, as they do not internalize the effect of their decisions on the aggregate run probability. Dell'Ariscia, Laeven, and Marquez (2014), using a static bank model with oligopolistic competition, show that lower real interest rates increase banks' incentives to choose asset profiles with higher risk-return profiles. Finally, Martinez-Miera and Repullo (2017) show in a model with a systemic

risk metric that an increase of saving induces banks to economize on monitoring costs, thereby increasing banks' asset risk.

On the empirical side, numerous contributions assess the risk-taking channel using individual bank risk metrics, of either assets or liabilities, or banks' balance sheet variables. Some papers use information on changes in lending standards, for instance from rating agency estimates (Altunbas, Gambacorta, and Marques-Ibanez 2014). Others use credit registries information on default histories (Jiménez et al. 2014; Ioannidou, Ongena, and Peydró 2015; Altavilla, Boucinha et al. 2019) or banks' internal ratings on loans (Dell'Ariccia, Laeven, and Suarez 2017). Finally, some papers examine risk information from syndicated loans (Aramonte, Lee, and Stebunovs 2015). In contrast to these, we examine the impact on so-far neglected systemic risk metrics.

All of the above papers employ microeconomic panel data analysis but neglect the time-series dimension. Accounting for the endogenous response of monetary policy is important, however. Some papers do so using VAR methodologies. These include Buch et al. (2014a, 2014b), who focus on asset risk, and Angeloni, Faia, and Lo Duca (2015), who focus on liability risk. None of those papers examines the impact on systemic risk. And none takes up both a multicountry and a time-series perspective. Moreover, our work is, to the best of our knowledge, the first in this line of research to employ recently developed VAR techniques that make use of external information from market responses around monetary policy announcements.¹⁰ Moreover, we also employ this information in local projection methods,¹¹ adding to the robustness of our results.

Finally, our paper is related to the growing literature on empirically measuring the effects of macroprudential policy. Most papers study the effects of changes in macroprudential measures on financial or economic conditions directly, usually employing macro data for a panel of countries (Kim and Mehrotra 2018, 2019; Alam et al. 2019; Richter, Schularick, and Shim 2019; Schryder and Opitz 2019).

¹⁰See Gürkaynak, Sack, and Swanson (2005) for early work, Gertler and Karadi (2015) for the first proxy VAR approach to monetary shock identification, and more recently Miranda-Agrippino and Ricco (2021), Anderson and Cesa-Bianchi (2020), and Jarocinski and Karadi (2020). For a euro-area context, see Altavilla, Brugnolini et al. (2019) and Corsetti, Duarte, and Mann (2018).

¹¹See Jordà (2005).

However, there is some evidence of effects on the firm level as well (Ayyagari, Beck, and Peria 2018). Fewer papers study the interaction of macroprudential measures with monetary policy. For instance, Everett et al. (2019) do so in a euro-area context, while Coman and Lloyd (2019) do so for U.S. shocks. Our methodology builds on theirs, but—differently from them—we control for non-monetary shocks contained in market responses to policy announcements. More fundamentally, however, we are again concerned with the interaction of monetary and macroprudential policies on systemic risk measures rather than on lending volumes, as they are.

A number of policy implications emerge from our analysis. Measures of systemic risk can, for instance, be employed as variables actively monitored by policymakers. Also, since systemic risk is affected by global banks in several countries, those types of financial spillovers call for more analysis on policy coordination. Further, there are implications for policy communication and announcements. Schularick, Ter Steege, and Ward (2020) find that discretionary and unanticipated monetary policy interest rate hikes trigger crises when enacted in a boom period with easy credit conditions and in small open economies with fixed exchange rate regimes. This is not inconsistent with the finding that prolonged periods of low interest rate favor risk-taking, especially in large economies like the United States. The latter can then materialize in a crisis whenever unexpected shocks (be it an interest rate hike or the sudden emergence of foreclosures that dries out the market for asset-backed securities) make excessive leverage unsustainable. Nor is it incompatible with the notion that announced and well-calibrated increases in interest rates do not necessarily trigger financial crises, if banks and markets are given time to adjust.

3. Monetary Policy and Systemic Risk

We start by establishing our main results, namely that contractionary monetary policy shocks reduce measures of systemic risk in a sample of global systemically important banks. In terms of methodologies, we use both a panel VAR and proxy VARs. In section 3.1 we employ the panel model that allows us to test the cross-country and cross-bank validity of the effect of monetary policy on systemic

risk. Hence, we can ascertain that the effects are not an artifact of certain institutions or particularities of certain countries' monetary policy. For the panel VAR we rely on traditional recursive identification schemes. Ideally, we would like to identify monetary policy shocks using high-frequency market responses around monetary policy announcements,¹² which are, however, not available for the full set of countries. Therefore, as an alternative and for robustness purposes, we estimate proxy VARs for the United States and the euro area. In these models, high-frequency market responses are used as external instruments to identify monetary shocks.¹³ We additionally take care to "cleanse" these responses from nonmonetary factors. Throughout, we test robustness of our results under various model assumptions, reported in online appendix A.2 (see online appendix at <http://www.ijcb.org>).

3.1 Panel VAR

3.1.1 Model Description

We denote as \mathbf{Y}_t the stacked version of the vector of G endogenous variables $\mathbf{y}_{i,t}$ so that $\mathbf{Y}_t = (\mathbf{y}'_{1,t}, \mathbf{y}'_{2,t}, \dots, \mathbf{y}'_{N,t})$, where $i = 1, \dots, N$ is the cross-sectional index and $t = 1, \dots, T$ is the time index. The structural panel VAR can then be written as

$$\mathbf{A}_0 \mathbf{y}_{i,t} = \mathbf{k} + \mathbf{A}(L) \mathbf{y}_{i,t-1} + \boldsymbol{\epsilon}_{i,t},$$

where $\mathbf{A}(L) = \mathbf{A}_1 + \mathbf{A}_2 L + \dots + \mathbf{A}_p L^{p-1}$ is a polynomial in the lag operator L for each cross-sectional unit i and k includes all deterministic components. The corresponding reduced-form VAR then is

$$\mathbf{y}_{i,t} = \mathbf{c} + \mathbf{B}(L) \mathbf{y}_{i,t-1} + \mathbf{u}_{i,t},$$

where $\mathbf{c} = \mathbf{A}_0^{-1} \mathbf{k}$, $\mathbf{B}(L) = \mathbf{A}_0^{-1} \mathbf{A}(L)$, and $\mathbf{u}_{i,t} = \mathbf{A}_0^{-1} \boldsymbol{\epsilon}_{i,t}$ such that \mathbf{A}_0^{-1} is the contemporaneous impact matrix of the mutually uncorrelated $G \times 1$ random disturbances $\boldsymbol{\epsilon}_{i,t}$.

We estimate the model via fixed effects by demeaning. In the panel VAR, we identify structural shocks by specifying the

¹²See Gürkaynak, Sack, and Swanson (2005), Altavilla, Brugnolini et al. (2019), or Jarocinski and Karadi (2020), among others.

¹³See Gertler and Karadi (2015).

impact matrix \mathbf{A}_0^{-1} as lower-triangular such that the ordering of the variables in the VAR implicitly identifies the shocks. As mentioned above, alternative high-frequency identification methods are employed further below. As is common in the literature, we order the variables as follows: macroeconomic controls, monetary policy rates, and risk metrics. This ordering implies that macroeconomic variables do not respond contemporaneously to structural monetary innovations, but that the largely market-based risk measures potentially do.

3.1.2 Data and Variables in the Panel VAR

We employ a monthly panel data set over the sample period 1992–2016 for 29 global systemically important banks (G-SIBs), as defined by the Bank for International Settlements,¹⁴ from 11 countries which we aggregate to seven cross-sectional units, namely the United States, United Kingdom, Japan, the euro area,¹⁵ China, Sweden, and Switzerland. All variables used in the analysis and their data sources are described in online appendix A.1.

The benchmark panel VAR specification is a model in log-levels, which includes logged CPI and GDP. The latter is interpolated using the Chow and Lin (1971) method with industrial production and retail sales as reference series. In addition to a monetary policy indicator, we add to our VAR two types of systemic risk metrics. The first metric, ΔCoVaR , quantifies the codependency of financial institutions on each other's health. Technically, ΔCoVaR measures the contribution of each institution to systemic risk as the difference between the value-at-risk of the system when the bank in question is in distress relative its median state. Intuitively, it measures the extent to which each bank contributes to systemic risk through its connection to the rest of the system. We estimate this metric using equity returns as well as CDS spreads. The second metric we consider is the long-run marginal expected shortfall (LRMES), which measures how much equity would be needed to cover losses in the event of a systemic crisis. Hence, this measure is more apt

¹⁴See table A.1 in online appendix A.1.

¹⁵Spain, Germany, France, Italy, and the Netherlands share the same monetary policy and are hence subsumed under the euro area.

to capture exposure of a particular institution to ensuing fire sales or other pecuniary externalities stemming from asset commonality. More details on both types of risk metrics are available in online appendix A.1.3. Due to the extended ubiquity of the zero lower bound, we use shadow rates as policy instruments whenever available.¹⁶ More concretely, we use the shadow rates from Krippner (2013), which have been computed for the United States, United Kingdom, Japan, and the euro area.¹⁷

3.1.3 Results for the Panel VAR

Figure 1 shows estimated impulse responses to an exogenous increase in the interest rate for all seven countries in a model with 12 lags.¹⁸ The sequence of panels in each row of the figure represents the impulse responses of the four-variable VAR with different risk metrics, namely ΔCoVaR based on equity returns, ΔCoVaR based on CDS spreads, and LRMES. The time sample is 1992:06–2016:12 for the two ΔCoVaR measures and 2000:06–2016:12 for the LRMES metric. The latter is not available earlier.¹⁹

In each model, GDP and the price level fall persistently after a few months, with prices featuring only a small and short-lived initial increase.²⁰ More central to the question at hand, all risk metrics fall significantly in all three models, albeit with somewhat different patterns. As mentioned earlier, the two measures capture different aspects of the transmission of individual bank risk to the

¹⁶Shadow rates can track monetary policy rates in normal times but also when the main policy rate remains near zero.

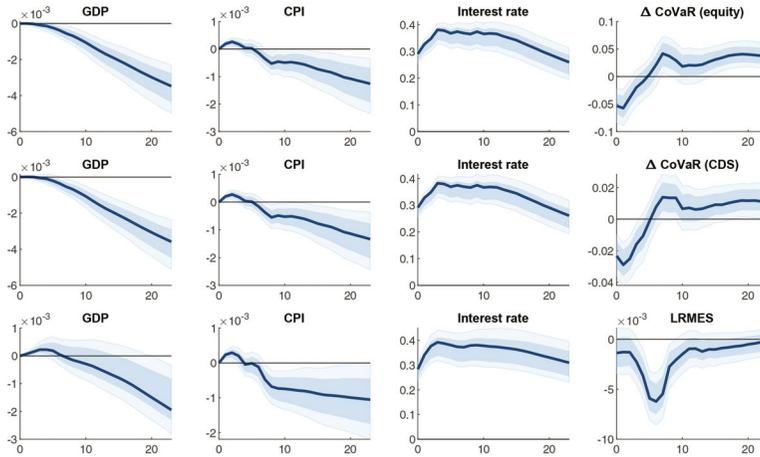
¹⁷For the remaining countries, we use the actual policy rates. During our sample period, these either never hit the zero lower bound (China), did so only briefly (Sweden), or adopted negative interest rates (Switzerland). Our results remain robust when using the shadow rate estimates by Wu and Xia (2016) and also when simply using policy rates.

¹⁸Lag length selection is guided by information criteria. The Akaike information criterion prefers 12 lags with a modest gain of going beyond 3 lags, as preferred by the Schwarz Bayesian criterion. We use 12 lags to account for the rich dynamics in our time series, but we check robustness with fewer lags.

¹⁹We verify that our results remain robust when we harmonize the estimations to start in mid-2000.

²⁰This “price puzzle” is commonly observed using recursive identification schemes (see, for instance, Ramey 2016) and, *inter alia*, motivates our use of a proxy VAR setting below.

Figure 1. Panel VAR



Notes: Impulse responses in the panel VAR(12) to a monetary policy shock. Each row represents a VAR with a different risk metric (ΔCoVaR based on equity returns in the first row, ΔCoVaR based on CDS in the second, and LRMES in the third). Countries included: United States, Japan, United Kingdom, China, euro area (Germany, France, Spain, Netherlands, Italy), Sweden, and Switzerland. Time sample: 1992:06–2016:12 for ΔCoVaR measures and 2000:06–2016:12 for LRMES. Shaded areas indicate 68 percent (dark) and 90 percent (light) confidence bands using bootstrapped cross-sectional system robust standard errors.

system. ΔCoVaR captures particularly a transmission that takes place through network connections, while movements in LRMES are more closely associated with pecuniary externalities. Beyond that, the two measures also potentially capture the dynamics of systemic risk at different horizons. Both ΔCoVaR measures show most of their decline on impact, while the LRMES response is more hump-shaped, reaching its peak after about six months.

These results indicate that changes in the stance of monetary policy are not innocuous for the level of systemic risk of globally important financial institutions. In order to appreciate the relevance of our estimates, we compare their magnitude with previous studies in the microeconomic literature (reviewed in section 2) and find substantially stronger effects. In Altunbas, Gambacorta, and Marques-Ibanez (2014), Jiménez et al. (2014), and Dell’Ariccia, Laeven, and Suarez (2017), the marginal effect of a one-standard-deviation increase in the interest rate measure lies roughly at 0.1 to

0.13 standard deviations of their respective bank risk variable. Performing similar computations based on the maximum response of the three systemic risk variables considered, our results suggest that a one-standard-deviation shock to the interest rate decreases systemic risk by roughly 0.66 (ΔCoVaR) to more than one (LRMES) standard deviations. Differences in methodologies notwithstanding, we interpret these much larger effects as pointing to important macroeconomic externalities and contagion channels in the transmission of monetary shocks.

3.1.4 Robustness and Extensions

We verify robustness of our main results along several dimensions. In figure A.3 in online appendix A.2, all three risk measures continue to decline significantly when the lag length is reduced to 3, as preferred by the Schwarz Bayesian criterion, or indeed to any other number between 4 and 12. Figure A.2 shows that systemic risk responses to a monetary tightening are similar when we use actual policy rates instead of shadow rates. The same is true when using shadow rate estimates by Wu and Xia (2016). Figure A.4 confirms our results for the pre-crisis period. Finally, in earlier versions of the paper we verified our findings for panel VAR specifications in growth rates, with linear time trends and crisis dummies, and when using a mean-group estimator,²¹ as well as under a FAVAR model for the U.S. economy.

3.2 Proxy VAR Using External Instruments

Identification is of critical importance in the estimation of any structural VAR model. For this reason we also test our results under recently developed and more rigorous methodologies for monetary policy shock identification. These generally consist of feeding external information into the VAR. Most often, building on early works of Kuttner (2001) and Gürkaynak, Sack, and Swanson (2005), monetary policy shocks are identified based on high-frequency movements in futures or swap prices around monetary policy meetings or press

²¹See Pesaran and Smith (1995). This specification alleviates concerns of parameter biases stemming from heterogeneity in the coefficient matrices across countries.

conferences. These surprises indicate new information to market participants that was not priced into futures contracts before the monetary policy announcements. Since they are therefore orthogonal to consensus market expectations of future macroeconomic developments, endogeneity concerns are argued to be significantly alleviated.

We follow the approach in Gertler and Karadi (2015) and include market surprise series as an instrument in a proxy VAR for the United States and the euro area. This framework is useful not only in addressing endogeneity concerns in general, but is especially suitable for our analysis based on financial market variables. Since in the benchmark panel VAR our risk measures are ordered after interest rates, they are allowed to contemporaneously respond to policy innovations. In turn, however, this recursive ordering precludes a response of policymakers to financial market stress. Such a restriction could potentially undermine the correct identification of structural monetary shocks. Using the proxy VAR approach allows us to overcome such a restriction and additionally use external information contained in the market surprise series.

3.2.1 Proxy VAR Model Description

Consider again the relation between the reduced-form and structural shocks,

$$\mathbf{u}_t = \mathbf{A}_0^{-1} \boldsymbol{\epsilon}_t,$$

now in a single-country VAR. We partition the shock vectors into those to monetary policy, indicated with a superscript p , and others, labeled with a superscript q . The corresponding vectors then read as follows: $\mathbf{u}_t = [u_t^p, \mathbf{u}_t^q]'$, $\boldsymbol{\epsilon}_t = [\boldsymbol{\epsilon}_t^p, \boldsymbol{\epsilon}_t^q]'$. Upon denoting the impact matrix \mathbf{A}_0^{-1} as \mathbf{S} , our interest lies in the set of coefficients, namely column \mathbf{s} , that measures the initial impact to a structural monetary policy shock $\boldsymbol{\epsilon}_t^p$.²² In what follows, we denote as \mathbf{s}^q the initial impact of $\boldsymbol{\epsilon}_t^q$ on \mathbf{u}_t^q , while s^p is the corresponding impact on the reduced-form monetary policy residual u_t^p .

²²We may therefore leave the remaining columns of \mathbf{S} undetermined.

Building on Mertens and Ravn (2013) and Stock and Watson (2018) and following Gertler and Karadi (2015), we use high-frequency market responses as an external instrument in the proxy VAR to identify the structural innovations ϵ_t^p . For these instruments to be valid, the surprise series \mathbf{Z}_t needs to be *relevant* and *exogenous* as follows:

$$\mathbb{E}[\mathbf{Z}_t \epsilon_t^{p'}] = \phi \neq 0, \quad (1)$$

$$\mathbb{E}[\mathbf{Z}_t \epsilon_t^{q'}] = 0. \quad (2)$$

To estimate impulse responses from the model

$$\mathbf{Y}_t = \mathbf{B}(L)\mathbf{Y}_{t-1} + \mathbf{s} \epsilon_t^p,$$

we obtain estimates of \mathbf{s} . We do so as follows. We first extract the residuals, \mathbf{u}_t , from the reduced-form VAR. These are then used in a two-stage least-squares regression which include \mathbf{Z}_t as instruments. In the first stage, u_t^p is linearly projected on \mathbf{Z}_t . This delivers the fitted values \hat{u}_t^p . The latter, which is orthogonal to the remaining shocks ϵ_t^q , can be used in the second-stage regression:

$$\mathbf{u}_t^q = \frac{\mathbf{s}^q}{s^p} \hat{u}_t^p + \boldsymbol{\xi}_t.$$

The above procedure ensures that $\frac{\mathbf{s}^q}{s^p}$ is consistently estimated and can be used to obtain \mathbf{s} . As is common, we normalize s^p so that the initial interest rate response is equal to 1 percentage point. We estimate the proxy VAR via Bayesian methods, as now the number of observations is considerably smaller than in the panel VAR. Details are given in online appendix A.1.4.

3.2.2 Isolating Policy Shocks from Confounding Factors

A recent literature noted that, in the presence of information asymmetries between the central bank and market participants, market responses during the narrow window around monetary policy announcements could be contaminated by “information shocks” (Melosi 2017; Jarocinski and Karadi 2020; Miranda-Agrippino and Ricco 2021; and Nakamura and Steinsson 2018). This would, for

instance, happen if the central bank has an informational advantage concerning the macroeconomy or the fundamental shocks hitting it. This additional information would be revealed, alongside any exogenous monetary shock alone, during the policy announcements.

For instance, an increase in expected future short-term interest rates during the central bank's press conference might in numerous instances reflect the market's assessment that the central bank considers the economy to likely perform more favorably than anticipated. One sign of such an effect would be a contemporaneous increase in the price of risky assets such as stocks. If the researcher then simply used the changes in expected interest rates as an instrument in a proxy VAR, the exogeneity assumption (1) is likely to be violated. The researcher would then measure not the impulse response to an actual exogenous monetary policy shock but instead that to some combination of fundamental shocks the central bank responds to. Based on this reasoning, we purge our shocks as follows.²³

For the United States, we follow Miranda-Agrippino and Ricco (2021), who regress the commonly used changes in expected federal funds rates, based on futures contracts with an average maturity of about three months (FF4), on the Federal Reserve's Greenbook forecasts and their revisions. These forecasts reflect the Fed's assessment of the current and future state of the macroeconomy. However, since they are released with a lag of five years, the residuals from the regression are argued to contain those changes in expected interest rates that are primarily due to exogenous innovations in the stance of policy.

Ideally, we would like to use the same approach for the euro area. However, in this case an equivalent to Greenbook forecasts is not available. Therefore, for the euro area we adapt the procedure in Jarocinski and Karadi (2020). More precisely, we take the time series of interest rate *and* stock market index responses around monetary policy announcements and feed them into a sign-restriction

²³Some authors have recently argued against the prevalence of central bank informational advantages; see, for instance, Bauer and Swanson (2020) and Hoesch, Rossi, and Sekhposyan (2020). However, for our purpose all that is needed is to isolate pure monetary shocks from any other confounding factors revealed during the announcement. Moreover, we verify our results when using the noncleansed interest rate series.

procedure. We then select the median-target series of those shocks as exogenous monetary innovations that lead to changes in interest rates and stock prices in opposite directions, in line with standard theory.²⁴

3.2.3 *Data and Variables in the Proxy VAR*

The proxy VAR includes the same set of variables as the panel VAR. Instead of the shadow rates, we use interest rates with three months to two years maturity. This allows us to take into account the increased importance of communication policy adopted more aggressively by U.S. and euro-area monetary authorities and their commitment to maintain short-term rates at the zero lower bound.²⁵ As external instruments we use the shock series by Miranda-Agrippino and Ricco (2021) for the baseline U.S. model. For the euro area, we rely on our instrument series computed from data of changes in one-year OIS (or German government bond) yields and the Euro Stoxx 50 index around ECB announcements taken from the monetary shock database of Altavilla, Brugnolini et al. (2019).²⁶

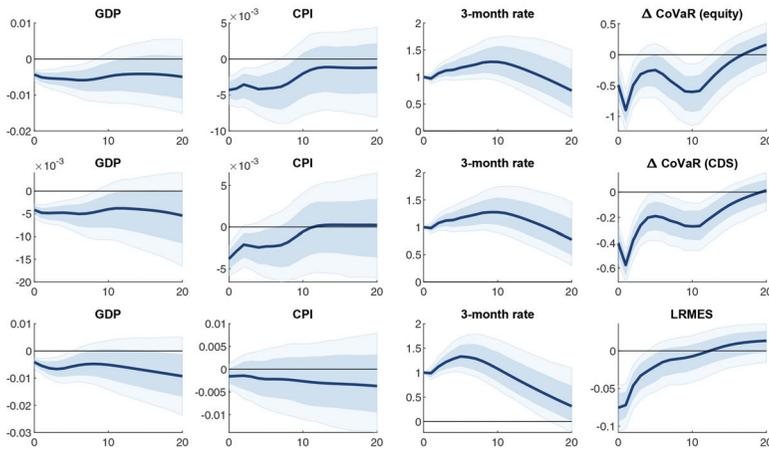
3.2.4 *Results for the Proxy VARs*

Figure 2 shows impulse responses for the U.S. economy to a contractionary monetary policy shock. In line with the panel VAR, output and prices decline. However, here they do so significantly on impact; price and output puzzles are absent. More importantly, all three risk measures significantly decline, confirming our results so far. The proxy VAR also features somewhat richer dynamics of the risk variables. LRMES declines now on impact, while both ΔCoVaR metrics exhibit a second decline after around six months. Notably,

²⁴We make sure that our results are not driven by differences in these two approaches, as we verify them in a robustness exercise when cleansing via stock market responses for the U.S. model as well.

²⁵The exact choice of interest rate maturity is adjusted based on the country and time period.

²⁶In robustness exercises, we use the surprise data provided in Cieslak and Schrimpf (2019). We employ the one in Altavilla, Brugnolini et al. (2019) as a benchmark, as their window includes press statements and conferences in a single *monetary event window*. Details on shock aggregation are given in online appendix A.1.4.

Figure 2. U.S. Proxy VAR

Notes: Impulse responses in monthly U.S. VAR(12) to a monetary policy shock identified using high-frequency market responses of three-month federal funds futures rate (adjusted for information dissemination effects as in Miranda-Agrippino and Ricco 2021) around monetary policy announcements as external instruments. Time sample: 1992:06–2016:12 for ΔCoVaR measures and 2000:06–2016:12 for LRMES, which is estimated in a VAR(6). Shaded areas indicate 68 percent (dark) and 90 percent (light) credible sets.

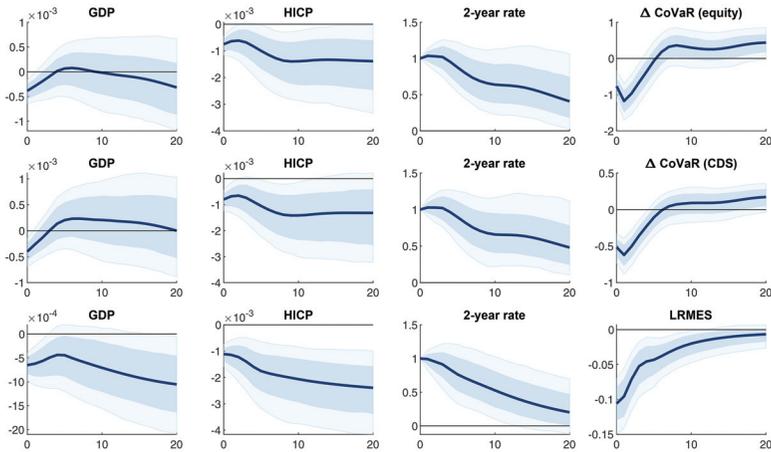
risk responses are quantitatively more pronounced than in the panel VAR, even when controlling for the (normalized to 100 basis points) initial interest rate impact.

Figure 3 shows the same set of responses for the euro area. Also in this case, price or output puzzles are absent. Once again all three systemic risk measures decline. Quantitatively, the response of the risk metrics is even stronger for the euro area than in the U.S. model. This, however, results from the use of longer-term interest rates, which reflect innovations along a larger portion of the yield curve.²⁷

3.2.5 Robustness and Extensions

Once again we check robustness along several dimensions also for the proxy VAR. First, figures A.5 and A.6 in online appendix A.2 show

²⁷We verify this when harmonizing the shock cleansing procedure and then using longer-term interest rates for the U.S. model as well, which results in quantitatively very similar responses. See also section 4.

Figure 3. Euro-Area Proxy VAR

Notes: Impulse responses in monthly euro-area VAR(12) to a monetary policy shock identified using high-frequency market responses of one-year OIS rate (source: Altavilla, Brugnolini et al. 2019) around monetary policy announcements as external instruments (adjusted for information dissemination effects using stock price responses as in Jarocinski and Karadi 2020). Time sample: 1999:01–2016:12 for Δ CoVaR measures and 2000:06–2016:12 for LRMES, which is estimated in a VAR(6). Shaded areas indicate 68 percent (dark) and 90 percent (light) credible sets.

results when adding an excess bond premium and a stock market index to both models, as is often done in the literature. The response of systemic risk is slightly less persistent in the U.S. model, but otherwise hardly changed. Results remain robust when adding exchange rates or the VIX, when using flat priors and mostly when estimating the models over the pre-crisis sample (figures A.7 and A.8). Also, we verify our results when cleansing the U.S. shocks on our own (figure A.9) and when using alternative instrument data for the euro area (figure A.10). Finally, figures A.11 and A.12 show that our results remain robust even when we abstain from cleansing the surprise series and simply use interest rate changes around monetary policy meetings as instruments in the proxy VAR.

To sum up, the use of external instruments confirms and strengthens our evidence of an impact of monetary policy on systemic risk. This leads us to examine the role of policy spillovers

across countries and the role of complementarities between monetary and macroprudential tools, which we do in sections 4 and 5, respectively. Before closing this section, however, we estimate two additional sets of specifications. First, we examine the response of a forward risk measure, namely forward- Δ CoVaR. Second, we include in our proxy VARs measures of bank leverage to see how much of the impact on systemic risk can be attributed to balance sheet rebalancing as opposed to changes in market valuations.

3.2.6 *Forward- Δ CoVaR*

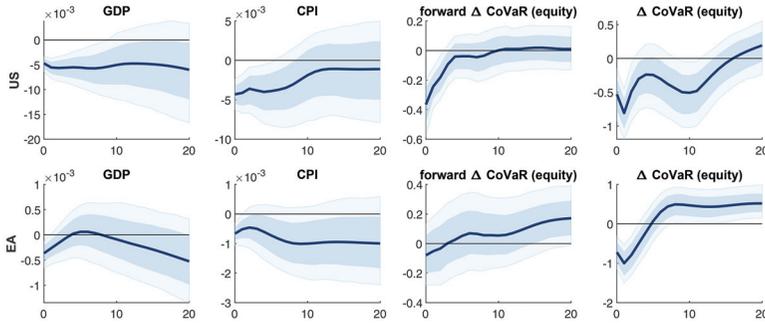
Generally speaking, monetary policy has an impact on both current variables and expectations, both with respect to inflation or measures of systemic risk. It is even more relevant in a case like the buildup of financial risk, as this likely takes place over extended periods of time. It is therefore instructive to add to our proxy VARs a forward measure of systemic risk. This is possible in the case of the Δ CoVaR metric, as Adrian and Brunnermeier (2016) provide both a real-time and a forward- Δ CoVaR. We follow their example and compute a two-year forward measure,²⁸ and then reestimate the proxy VAR for both the United States and the euro area. The VAR specification which we show includes both the Δ CoVaR and the forward forward- Δ CoVaR, though results remain robust when we only include the forward Δ CoVaR. The specification which includes both is akin to one in which an outcome variable and expectations of it are entered: in parallel with traditional monetary policy transmission channels, the latter could react differently depending on the expectation formation process. Results are shown in figure 4.

We see that the forward measures fall on impact, albeit significantly so only in the U.S. case.²⁹ But the most interesting aspect is the comparison of the response with the real-time systemic risk metric. For the United States, the latter falls and features a second decline after several months. On the contrary, the forward measure

²⁸Details on the computation are provided in online appendix A.1.

²⁹We note that these results depend to a larger extent on the particularities of computing the forward measure than is the case for the real-time metric, e.g., with respect to the forecast horizon. Also, we find the forward measure in the euro-area model to fall significantly when using German government yields instead of OIS rates in the construction of the instrument.

Figure 4. U.S. and Euro-Area Monetary Policy Shocks in Proxy VARs Including Forward- Δ CoVaR



Notes: Impulse responses to a monetary policy shock in U.S. (top) and euro-area (bottom) proxy VARs with forward- Δ CoVaR as additional variable. Remaining details as in figures 2 and 3, respectively.

falls only on impact. The delayed response of the real-time measure captures precisely the notion that the transmission of monetary policy to risk tends to materialize also at medium-term horizons, which the forward measure is meant to predict. For the euro area the impact of the policy rate on the forward measure is much milder, while the impact on the real-time measure does not show a second delayed decline. While it is not possible to draw conclusions with general validity from this particular exercise, we conjecture that the differences between the United States and the euro area are suggestive of different prudential and institutional backgrounds. It is generally true that the transmission of monetary policy to expectations can be strengthened or dampened by the particularities of agents' expectation formation processes, by country-specific institutions or actions of national policy bodies. Macroprudential policy, for instance, studied in more detail in section 5, is organized at the national level in Europe. With banks being residents in different countries, expectations and decisions of their executive managements might differ depending on the country-specific environment.

3.2.7 The Role of Bank Leverage

As mentioned earlier, an extensive literature has looked at the impact of low interest rates on banks' lending standards, at the

individual bank level,³⁰ at the aggregate level,³¹ or on banks' search for yield behavior.³² In all those cases, atomistic banks take actions, which could be privately efficient, albeit failing to internalize the consequences of their decisions on others. In the aggregate, however, banks' individual decisions might cancel out. Changes in systemic risk would materialize either if banks' actions change the aggregate composition of the balance sheet, with excessive leverage, or if collectively they affect prices, thereby triggering changes in market valuation, or both. A priori, our analysis is agnostic on which of those two channels prevails and a complete separation of the two might be elusive, as changes in market valuations might trigger second-round portfolio rebalancing by banks. Still, it is instructive to provide suggestive evidence on which of the two channels seem to prevail in the data. To this purpose we rerun our proxy VAR for both the United States and the euro area and include bank book leverage.³³ This measure should, at least for some period, be immune to changes in market prices, and in general should be more directly linked to banks' active balance sheet adjustments in response to changes in interest rates. Our results (see figure 5) show that in response to a monetary tightening, book leverage tends to decline, albeit somewhat less significantly so than the systemic risk metrics.³⁴ Hence, banks individually and collectively tend to leverage less and to expose themselves less to liability risk. However, one observation that stands out is that the impact of monetary shocks on systemic risk is unaltered even when adding measures of banks' balance sheets that respond in line with the risk-taking channel. Further, we note that the response of book leverage is not sizable compared with the change observed in our systemic risk measures.

At last, it is plausible that the mild response of book leverage might be linked to the fact that this ratio is particularly highly

³⁰See Dell'Ariccia, Laeven, and Marquez (2014) and Jiménez et al. (2014).

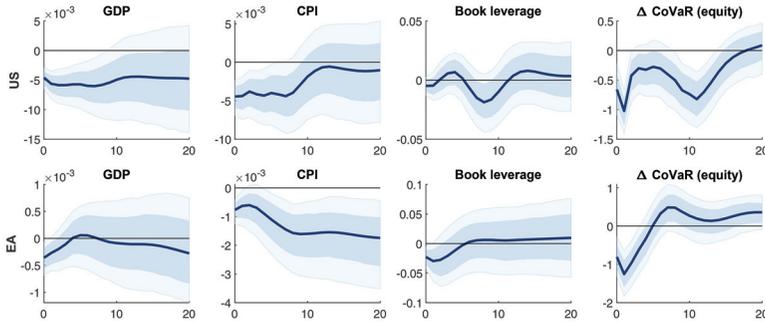
³¹See Neuenkirch and Nöckel (2018).

³²See Becker and Ivashina (2015).

³³Details on the computation are provided in online appendix A.1.

³⁴Our results are in line with Miranda-Agrippino and Rey (2020), who also find some evidence that bank leverage of U.S. and European G-SIBs falls after contractionary U.S. monetary shocks. As in the case of the forward- Δ CoVaR, we observe that differences in measurement of the book leverage series, e.g., related to weighting, sometimes somewhat alter the responses.

Figure 5. U.S. and Euro-Area Monetary Policy Shocks in Proxy VARs Including Book Leverage



Notes: Impulse responses to a monetary policy shock in U.S. (top) and euro-area (bottom) proxy VARs with book leverage as additional variable. Remaining details as in figures 2 and 3, respectively.

regulated. We therefore also consider an alternative VAR specification which, instead of leverage, includes U.S. banks' short-term and wholesale funding ratio as an alternative balance sheet measure and find it to significantly fall in response to a monetary tightening.³⁵ The results indicate that part of the impact of monetary policy on systemic risk is plausibly channeled through adjustments in banks' balance sheet variables as well, on top of adjustment in market prices. Changes in short-term funding, however, indicate mainly a risk-taking channel on the liability side, as a fall in short-term funding corresponds to a decline in the risk of bank runs.

4. The Role of U.S. vs. Non-U.S. Monetary Policy

A growing literature stresses the importance of U.S. monetary policy in determining not only U.S. but also global monetary and financial conditions (Rey 2015; Miranda-Agrippino and Rey 2020). This notion stems primarily from the dominant role of the dollar in international markets. Since Bretton Woods, the U.S. currency has maintained a stable dominant role as vehicle and anchor currency.

³⁵Results are shown in figure A.13 for U.S. G-SIBs, for which long-enough time series on short-term funding are available. Details on the data are given in online appendix A.1.

With the recent financial globalization, the dollar has established a dominant role also within the banking system. Several authors have argued that global banks in several countries seek liquidity and issue international deposits in dollars (Bruno and Shin 2015 or Gopinath and Stein 2018). If so, U.S. monetary policy in particular can play a role for risk of global banks, which are key contributors of systemic risk. Hence one of the most compelling questions relates to the assessment of whether U.S. monetary policy spills over or contributes to bank risk relatively more than domestic policy. Related to that is the relative impact of U.S. and euro-area monetary policy on other countries' systemic risk.

4.1 *U.S. vs. National Shocks Based on the Panel VAR*

Our goal in this section is to assess the role of U.S. monetary policy shocks relative to domestic shocks for the panel of countries in our sample. To accomplish this objective, we need an econometric specification that can include both types of shocks. We achieve that goal by extracting the identified structural shocks from our panel VAR and by including them in a local projection specification (Jordà 2005). Impulse responses from the panel VAR itself represent the average responses to each country's own monetary shocks. In contrast, using local projection methods with the extracted shocks allows us to easily compare the risk responses with U.S. and domestic monetary shocks.

The econometric specification reads as follows:

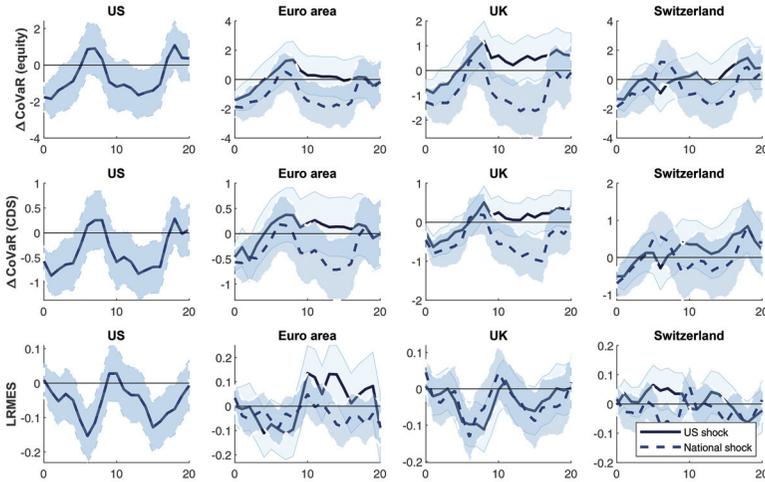
$$\mathbf{y}_{i,t+h} = \alpha_{i,h} + \beta_h \boldsymbol{\epsilon}_{s,t} + \sum_{j=1}^p (\gamma_h^y \mathbf{y}_{i,t-j} + \gamma_h^\epsilon \boldsymbol{\epsilon}_{s,t-j} + \mathbf{X}_{i,t-j} \Gamma_h^X) + \mathbf{e}_{i,t}, \quad h = 0, 1, \dots, H, \quad (3)$$

where $\boldsymbol{\epsilon}_{s,t}$, with $s \in (i, US)$, is the monetary policy shock; $\mathbf{y}_{i,t}$ indicates the risk measure; and $\mathbf{X}_{i,t}$ is a set of macroeconomic controls for country i .³⁶

Figure 6 shows the estimated impulse responses to both U.S. and domestic shocks. Rows refer to each of the risk metrics, while

³⁶We include each country's interest rate as well as logged GDP and CPI.

Figure 6. U.S. vs. Euro-Area Monetary Policy Shocks in Panel Local Projection



Notes: Impulse responses to U.S. (solid lines) and domestic (dashed lines) monetary policy shocks in panel local projection ($\{\beta_h\}_{h=0}^H$ in equation (3)). Shocks identified in the panel VAR as in figure 1. Time sample: 2000:06–2016:12. Shaded areas denote 90 percent VAR confidence bands using cross-sectional system robust standard errors.

columns refer to the countries. First and foremost, all risk measures reliably fall following a monetary tightening. ΔCoVaR features a second decline after less than one year. Notably, this corresponds remarkably well to the results from the U.S. proxy VAR in section 3.2. Turning to the relative importance of monetary policy spillovers, U.S. policy shocks do spill over to other countries but do not bear the dominant responsibility of the impact on systemic risk. Indeed, for the euro area and the United Kingdom, national monetary policy sometimes has a more pronounced impact on risk. In other words, for some economies, the impact of U.S. monetary policy does not outweigh that of the national policies. This seems reasonable given the dominant role of the U.S. dollar in global banking and international deposits primarily in countries with unstable inflation and exchange rates, rather than in the advanced economies in our sample.³⁷

³⁷See, for instance, the ECB’s (2019) report on the international role of the euro relative to the U.S. dollar.

Figure A.14 in online appendix A.2 reports *average* impulse responses to each country's own and U.S. shocks, respectively. Notwithstanding the heterogeneity uncovered so far, the average response to U.S. shocks is somewhat larger for the ΔCoVaR measures compared with domestic shocks.

4.2 *U.S. vs. Euro-Area Shocks Based on the Proxy VARs*

In parallel with the rest of the paper, we now test our results within the proxy VAR environment. Concretely, we add the risk variables of other countries to the U.S. and euro-area specifications and compare impulse responses. In order to ensure an accurate comparison, here we harmonize the two specifications. For the U.S. economy, we hence replace the shock series from Miranda-Agrippino and Ricco (2021) with one constructed following the procedure adopted for the euro-area proxy VAR.³⁸ Figure 7 shows impulse responses. Again, the systemic risk measures decline following both U.S. and the euro-area monetary policy shocks. Notably, the responses of LRMES are very heterogenous across countries, and in the euro area U.S. shocks have no significant effects on this measure.³⁹

In sum, we conclude that Fed policy does not seem to be the only driver of the global financial cycle when it comes to systemic risk metrics among globally important banks. Also, there seems to be noticeable heterogeneity in the responses of systemic risk measures to shocks in different monetary areas. These might originate from institutional differences or stem from differences in (local or financial) proximity of the country in question.

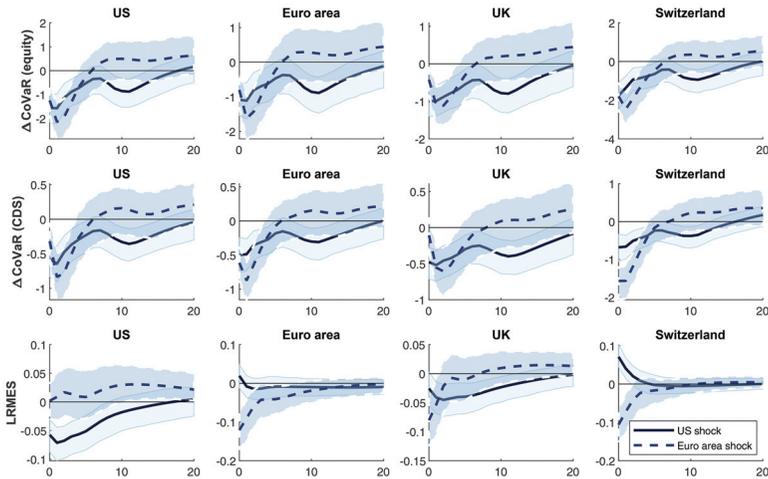
4.3 *Robustness*

As before, also in this case we perform robustness checks, mainly along the lines of shock identification and adding control variables. See online appendix A.2 for more details.

³⁸Hence, we use the same identification as in figure A.9 in a robustness check of our main results.

³⁹Note that impulse responses look smoother in this case due to the Bayesian estimation method and the recursivity of VAR impulse response functions.

Figure 7. U.S. vs. Euro-Area Monetary Policy Shocks in Proxy VARs



Notes: Impulse responses to a monetary policy shock in U.S. (solid lines) and euro-area (dashed lines) proxy VARs identified using high-frequency market responses of one-year rate (source: Cieslak and Schrimpf 2019 for United States, Altavilla, Brugnolini et al. 2019 for euro area) around monetary policy announcements as external instruments (adjusted for information dissemination effects using stock price responses as in Jarocinski and Karadi 2020). Time sample: 2000:06–2016:12. Shaded areas indicate 90 percent credible sets.

4.4 Discussion of Spillovers and the Role for Policy Coordination

Our results have important implications for a yet open debate on the extent of policy coordination for financial stability. Our data sample includes G-SIBs that operate in several countries. As ΔCoVaR by construction measures how distress of a particular institution affects the health of the other banks in the sample, in some sense already our results in section 3 could be interpreted as evidence of policy spillovers. For instance, a response of U.S. ΔCoVaR to U.S. monetary policy implies that Federal Reserve decisions affect the tail dependency of non-U.S. banks on U.S. G-SIBs. In this section, we have additionally established that there are spillovers of monetary policy to the risk metrics computed for global banks in other countries. With respect to ΔCoVaR we hence found that also, for

instance, U.S. monetary policy shocks affect the tail dependency of U.S. banks on, say, European G-SIBs. With regard to the LRMES metric, the interpretation is somewhat more straightforward in that we find U.S. and euro-area monetary shocks to also affect the systemic exposure of G-SIBs domiciled in other countries.

One way these spillovers could come about is through funding in global wholesale markets, which has been growing particularly before the financial crisis. Bruno and Shin (2015) rationalize a risk-taking channel occurring through refinancing in repo markets. When global banks apply more lenient conditions on local banks in supplying wholesale funding, e.g., in response to a monetary easing, the local banks transmit these conditions to their borrowers through greater availability of local credit. Hence, global liquidity is transmitted through the interactions of global and local banks through bank risk-taking. What our analysis highlights is that monetary policy decisions not only affect particular global-local bank relations but also the interdependence of globally active banks at the heart of this mechanism. This seems to be the case for measures of both contagion and systemic exposure and is not limited to shocks emanating from the United States.

At the current juncture, monetary policymakers do not explicitly take into account spillovers from or to foreign banks when setting interest rates. At the same time, macroprudential policies are largely national. Our findings suggest that for domestic policymakers there may be value in both monitoring activity of global banks as well as coordinating policy responses across jurisdictions. To what extent national macroprudential measures are successful in mitigating the effects of monetary shocks on systemic risk is examined in the following section.

5. Complementarity of Monetary and Macroprudential Policies

As the evidence on the risk-taking channel kept growing, concerns were raised in policy and academic circles regarding the unintended consequences of recent monetary easing measures. Notwithstanding the need for substantial monetary accommodation in the wake of the 2007–08 financial and sovereign debt crises in the euro area,

pundits have pointed to potentially detrimental effects of expansionary monetary policy on bank risk during boom phases. While monetary easing might stabilize the financial system following a crash, these measures, critics argue, might fuel future systemic banking crises. One response to those concerns has been that the effects on risk might be tamed by prudential policies. This view of policy complementarity entails that monetary policy should be concerned with its traditional role of price stability or demand stabilization, whereas in particular macroprudential policies should be devoted to deal with systemic risk.

This section tests this notion in our empirical time-series setup. First, we augment our baseline panel VAR with a macroprudential policy index by including an interaction term with the monetary policy measure. The objective is to examine how impulse responses to monetary policy vary when conditioning on “easy” or “tight” prudential regimes. Second, we again use extracted structural shocks in a local projections framework, which we augment with an interaction term of changes in macroprudential policy. Local projections are particularly well suited in this case since they easily accommodate the nonlinearities in the interaction of macroprudential and monetary policy that we wish to study. Furthermore, they allow us to quantify the impact on the monetary transmission of marginal changes in the prudential regime. We elaborate on this further below. Mirroring the two approaches used so far, we extract shocks from both panel and proxy VARs.

5.1 *Interacted Panel VAR*

To study policy complementarities in our panel of countries, we extend our VAR to include a macroprudential index as an interaction term with the interest rate measure. We use the *integrated macroprudential policy* (iMaPP) database recently released by the International Monetary Fund (IMF) (Alam et al. 2019). iMaPP represents the most detailed and comprehensive data set currently available and provides monthly information on changes in macroprudential measures of numerous countries in 17 different categories, such as capital and leverage requirements, loan loss provisions, liquidity regulation, various forms of borrowing limits, and reserve

requirements.⁴⁰ Changes to these are reported in indicator form, which we sum to produce a cumulative index for each country.⁴¹

Our panel VAR specification now reads as follows:⁴²

$$\mathbf{y}_{i,t} = \sum_{j=1}^p (\mathbf{B}_j \mathbf{y}_{i,t-j} + \mathbf{C}_j \mathbf{M}_{i,t-j-1} + \mathbf{D}_j \mathbf{y}_{i,t-j} \mathbf{M}_{i,t-j-1}) + \mathbf{u}_{i,t}, \quad (4)$$

where $\mathbf{M}_{i,t}$ is the macroprudential index for economy i at time t . We include this with a lag to address endogeneity concerns. $\mathbf{Y}_{i,t} \mathbf{M}_{i,t-1}$ is the interaction term between monetary and macroprudential policy. \mathbf{C}_j is the coefficient vector on the index, and the \mathbf{D}_j matrices contain the coefficients of the interaction terms. As we are primarily interested in the response to monetary shocks, we interact only the interest rate measure in the model with the macroprudential index.

In order to investigate whether the macroprudential regime alters the impact of monetary shocks on systemic risk, we compute impulse responses to a monetary policy shock conditional on an “easy” (low macroprudential index) and a “tight” (high macroprudential index) regime. We choose, respectively, the 20th and 80th percentile of the distribution of the index across countries in the sample and write the model as

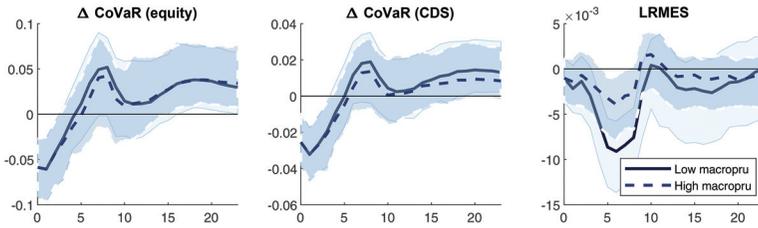
$$\begin{aligned} \mathbf{y}_{i,t}^{high} = & \sum_{j=1}^p (\hat{\mathbf{B}}_j^{high} \mathbf{y}_{i,t-j} + \hat{\mathbf{C}}_j^{high} \mathbf{M}_{i,t-j-1}^{high} \\ & + \hat{\mathbf{D}}_j^{high} \mathbf{y}_{i,t-j} \mathbf{M}_{i,t-j-1}^{high}) + \hat{\mathbf{u}}_{i,t}, \end{aligned} \quad (5)$$

⁴⁰We use all categories except those related to reserve requirements, as it is often not clear whether these should be considered prudential or monetary policy measures.

⁴¹The indexes are depicted in figure A.1 in online appendix A.1.

⁴²Our model specification builds on Towbin and Weber (2013) and Aastveit, Natvik, and Sola (2017). Note that we are not interested in identifying endogenous policy regimes, but rather in the response to monetary shocks conditional on the exogenous macroprudential environment. The parsimonious specification of the interacted VAR is best suited for this experiment.

Figure 8. Interacted Panel VAR with Macroprudential Index



Notes: Impulse responses to a monetary policy shock in the interacted panel VAR in “soft” (solid lines) and “tight” (dashed lines) macroprudential regimes. Shaded areas denote 90 percent confidence bands. Remaining details as in figure 1.

and

$$\begin{aligned}
 \mathbf{y}_{i,t}^{low} = & \sum_{j=1}^p (\hat{\mathbf{B}}_j^{low} \mathbf{y}_{i,t-j} + \hat{\mathbf{C}}_j^{low} \mathbf{M}_{i,t-j-1}^{low} \\
 & + \hat{\mathbf{D}}_j^{low} \mathbf{y}_{i,t-j} \mathbf{M}_{i,t-j-1}^{low}) + \hat{\mathbf{u}}_{i,t}.
 \end{aligned} \tag{6}$$

Regime-conditional impulse responses are then obtained simply by adding the vector of interaction coefficients, at their low and high values, to that row in \mathbf{A}_j that corresponds to the response of each endogenous variable to lagged interest rates. We then apply a standard Cholesky factorization to identify shocks recursively.

Figure 8 shows impulse responses for the risk metrics. In the “easy” macroprudential regime (solid lines), responses look very similar to the ones of the baseline panel VAR in figure 1. However, under tighter macroprudential policy (dashed lines), the LRMES responses are notably altered. The peak response is reduced by more than half. In contrast, for the ΔCoVaR metrics the tightness of the macroprudential regime does not seem to matter much.

So far results seem mixed. It is however possible that the role of policy complementarities is best captured within a model that more naturally lends itself to the study of nonlinearities. Moreover, the interacted panel VAR by construction allows us to study the response to monetary shocks conditional on the prudential regime, whereas the impact of prudential policy is perhaps most visible at

the margin. In order to address these concerns, in the next section we repeat the analysis for the panel of countries by employing local projection methods, again extended to include macroprudential interaction terms. Not least, this lets us use the shocks from the proxy VAR based on more sophisticated instrumental-variable techniques.

5.2 Panel Interacted Local Projections

Technically, the local projection analysis with interacted policy tools is implemented as follows.⁴³ In a first step, we again extract structural shocks from our VARs and feed them into the following local projections:

$$\mathbf{y}_{i,t+h} = \alpha_{i,h} + \beta_h \boldsymbol{\epsilon}_{s_t} + \sum_{j=1}^p (\gamma_h^y \mathbf{y}_{i,t-j} + \gamma_h^\epsilon \boldsymbol{\epsilon}_{s,t-j} + \mathbf{X}_{i,t-j} \Gamma_h^X) + \mathbf{e}_{i,t}. \quad (7)$$

Second, the model is augmented with an interaction term between the structural shock and the marginal changes in the macroprudential regime:

$$\mathbf{y}_{i,t+h} = \alpha_{i,h} + \beta_h \boldsymbol{\epsilon}_{s_t} + \delta_h \boldsymbol{\epsilon}_{s_t} \times \mathbf{M}_{it-1} + \gamma_h^M \mathbf{M}_{it-1} + \sum_{j=1}^p (\gamma_h^y \mathbf{y}_{i,t-j} + \gamma_h^\epsilon \boldsymbol{\epsilon}_{s,t-j} + \mathbf{X}_{i,t-j} \Gamma_h^X) + \mathbf{e}_{i,t}, \quad (8)$$

where here $\mathbf{X}_{i,t}$ includes, next to the control variables in levels, also interaction terms with the macroprudential variable, $\mathbf{M}_{i,t-1}$. The latter takes a value of +1 under a macroprudential tightening, a value of -1 under an easing, and a value of 0 in the absence of changes in the preceding month in country i . Hence, in contrast to the interacted VAR in the previous section, this specification allows us to study the influence of marginal changes in the prudential regime. The coefficient of interest in (8) is δ_h . It measures the marginal contribution of changes in macroprudential policy to

⁴³We adapt the procedure in Coman and Lloyd (2019), who study the role of macroprudential policies in mitigating spillovers of U.S. monetary policy on emerging market credit volumes.

the effect of monetary policy on risk. More concretely, whenever β_h in (7) is negative, a positive and statistically significant δ_h implies that a change in macroprudential policy dampens the systemic risk response.

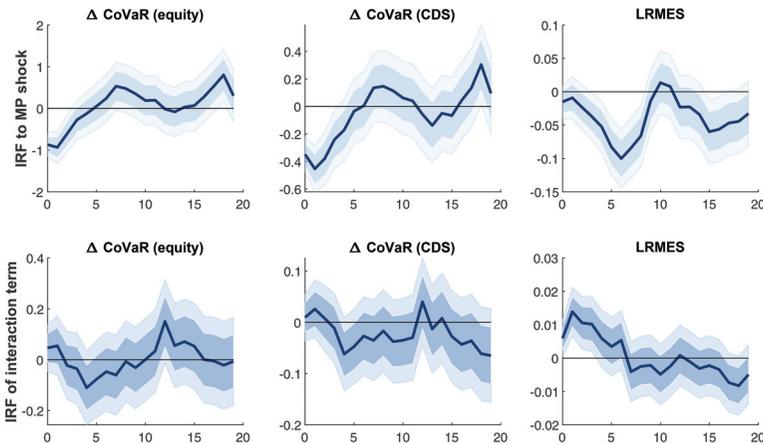
The methodology described lends itself to both panel and proxy VAR frameworks we have been using throughout. We check with both, for the reasons mentioned so far, namely having results robust to different identification schemes as well as being able to differentiate domestic from U.S. (and euro-area) shocks.

Figure 9 shows results for the first case in which the structural monetary shocks stem from the panel VAR, such that $s = i$ in (7) and (8). The upper panel depicts the sequence of coefficients $\{\beta_h\}_{h=0}^H$ in (7), hence implicitly for the case of no changes in the macroprudential regime, such that $\mathbf{M}_{i,t-1} = 0$. Reassuringly, these responses again look very similar to those in figure 1, in spite of the different methodologies. The lower panel of figure 9 shows the sequence of interaction coefficients $\{\delta_h\}_{h=0}^H$ in (8). For both ΔCoVaR measures the coefficients are mostly insignificant. In contrast, the LRMES coefficients clearly lie significantly above zero for some time. Hence again a tight macroprudential policy helps to mitigate the effects primarily on the LRMES measure.

Results so far are based on the panel VAR framework and therefore measure the effect of macroprudential measures to “one’s own” monetary policy. In light of the sometimes notable differences in responses to U.S. and non-U.S. shocks uncovered in section 4, we are interested in testing the impact of macroprudential policy also in our proxy VAR setup. Not least, this seems desirable, as there we can identify structural monetary shocks particularly well. To that end, we extract the shocks from both proxy VAR models and feed them into (7) and (8), such that now $s = US$ and $s = EA$, respectively.⁴⁴ In figure 10, for the U.S. shocks, we again find that risk responses to monetary tightening shocks are significantly negative and look similar to before. More importantly, the lower panel reveals that macroprudential policy in this case mitigates the effects of monetary shocks both on the LRMES and on the ΔCoVaR measures.

⁴⁴Extracting the structural shocks is slightly more involved than in the panel VAR with recursive identification since in the proxy VAR setting only one column of the impact matrix S is identified; see Piffer (2016).

Figure 9. Panel Local Projections with Macroprudential Interaction, with Shocks Identified in Panel VAR

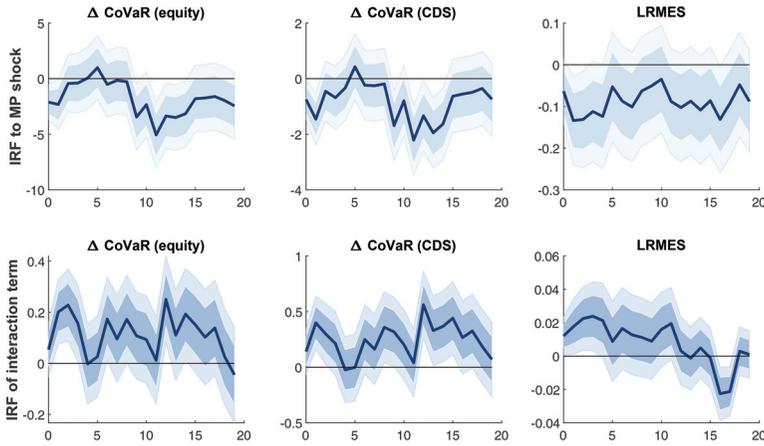


Notes: Upper panel: Impulse responses of monetary policy shock ($\{\beta_h\}_{h=0}^H$ in equation (7)). Lower panel: Impulse responses of interaction term of monetary and macroprudential policies ($\{\delta_h\}_{h=0}^H$ in equation (8)). Shocks extracted from panel VAR as in figure 1. Time sample: 1992:06–2016:12 for ΔCoVaR measures and 2000:06–2016:12 for LRMES. Shaded areas indicate 68 percent (dark) and 90 percent (light) confidence bands using cross-sectional system robust standard errors.

Finally, figure 11 shows results for the euro-area shocks. For this case again the mitigating effect seems to apply mainly to the LRMES measure. We conjecture that these differences might stem from the different concepts of systemic risk that the two metrics attempt to measure. Our results indicate that, for non-U.S. shocks, macroprudential policy seems to be primarily suited to shield banks from systemic distress, e.g., arising from pecuniary externalities. In contrast, macroprudential policy also seems to play a role in preventing contagion, e.g., arising from network effects, when it comes to U.S. shocks that drive funding conditions in global wholesale markets.

To sum up, we conclude from this section that macroprudential policy potentially plays a non-negligible role in mitigating the unintended consequences of monetary policy on systemic risk. While, in particular, U.S. policy seems to be mitigated significantly for all three risk measures, national and euro-area monetary shocks are

Figure 10. Panel Local Projections with Macroprudential Interaction, with Shocks Identified in U.S. Proxy VAR



Notes: Upper panel: Impulse responses of monetary policy shock ($\{\beta_h\}_{h=0}^H$ in equation (7)). Lower panel: Impulse responses of interaction term of monetary and macroprudential policies ($\{\delta_h\}_{h=0}^H$ in equation (8)). Shocks extracted from U.S. proxy VAR as in figure 2. Time sample: 1992:06–2016:12 for ΔCoVaR measures and 2000:06–2016:12 for LRMES. Shaded areas indicate 68 percent (dark) and 90 percent (light) confidence bands using cross-sectional system robust standard errors.

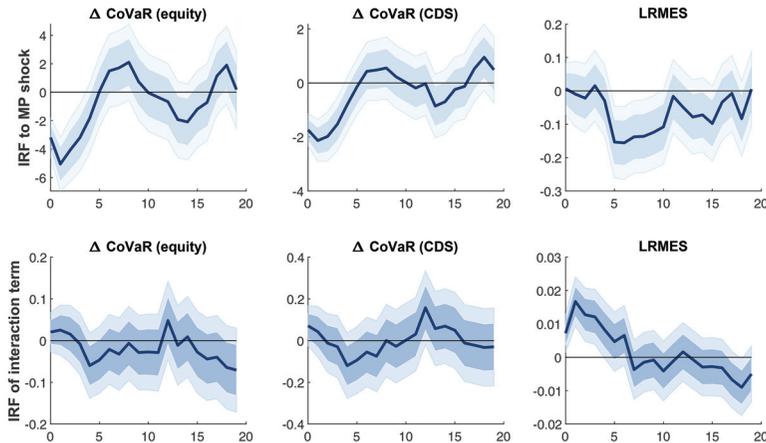
dampened, at least with respect to their effect on marginal shortfall measures.

6. Conclusion

Using both cross-country and time-series variation, we find novel and robust evidence that monetary policy shocks have an impact on systemic risk. So far the literature on the risk-taking channel of monetary policy focused on the bank-individual risk metrics and balance sheet variables. No evidence had been gathered on the potential systemwide consequences of monetary policy on risk, which can materialize through bank network connections or pecuniary externalities.

Given our findings, we examine implications for monetary policy spillovers across countries and for complementarities between

Figure 11. Panel Local Projections with Macroprudential Interaction, with Shocks Identified in Euro-Area Proxy VAR



Notes: Upper panel: Impulse responses of monetary policy shock ($\{\beta_h\}_{h=0}^H$ in equation (7)). Lower panel: Impulse responses of interaction term of monetary and macroprudential policies ($\{\delta_h\}_{h=0}^H$ in equation (8)). Shocks extracted from euro-area proxy VAR as in figure 3. Time sample: 1992:06–2016:12 for ΔCoVaR measures and 2000:06–2016:12 for LRMES. Shaded areas indicate 68 percent (dark) and 90 percent (light) confidence bands using cross-sectional system robust standard errors.

prudential and monetary tools. In light of the dominant role of the dollar, we quantify the impact of Fed policy, relative to domestic and euro-area shocks, in our panel of developed countries. It has indeed been argued that the Fed policy spillovers might be more pronounced due to the dominant international role of the dollar. We find that domestic shocks matter and that Fed and ECB policy spillovers are roughly at par. We conjecture that the reason lies with our panel of countries that comprises developed countries, while the U.S. dollar is relatively more predominant in the banking systems of countries with unstable inflation and exchange rates.

Finally, we examine whether macroprudential policies can tame the effects of monetary policy on systemic risk. We find that this is mostly the case for the LRMES metric, but we also find effects for our ΔCoVaR measures when considering U.S. shocks. Overall, we

interpret our findings as evidence that macroprudential policy may indeed be able to alleviate at least some of the spillovers of monetary policy to systemic risk that we document.

References

- Aastveit, K. A., G. J. Natvik, and S. Sola. 2017. "Economic Uncertainty and the Influence of Monetary Policy." *Journal of International Money and Finance* 76 (September): 50–67.
- Adrian, T., and M. K. Brunnermeier. 2016. "CoVaR." *American Economic Review* 106 (7): 1705–41.
- Alam, Z., A. Alter, J. Eiseman, R. G. Gelos, H. Kang, M. Narita, E. Nier, and N. Wang. 2019. "Digging Deeper—Evidence on the Effects of Macroprudential Policies from a New Database." IMF Working Paper No. 19/66.
- Allen, F., and D. Gale. 2000. "Financial Contagion." *Journal of Political Economy* 108 (1): 1–33.
- Altavilla, C., M. Boucinha, J.-L. Peydró, and F. Smets. 2019. "Banking Supervision, Monetary Policy and Risk-Taking: Big Data Evidence from 15 Credit Registers." Working Paper No. 1137, Barcelona Graduate School of Economics.
- Altavilla, C., L. Brugnolini, R. S. Gürkaynak, R. Motto, and G. Ragusa. 2019. "Measuring Euro Area Monetary Policy." *Journal of Monetary Economics* 108 (C): 162–79.
- Altunbas, Y., L. Gambacorta, and D. Marques-Ibanez. 2014. "Does Monetary Policy Affect Bank Risk?" *International Journal of Central Banking* 10 (1, March): 95–136.
- Anderson, G., and A. Cesa-Bianchi. 2020. "Crossing the Credit Channel: Credit Spreads and Firm Heterogeneity." Discussion Paper No. 2005, Centre for Macroeconomics (CFM).
- Angeloni, I., and E. Faia. 2013. "Capital Regulation and Monetary Policy with Fragile Banks." *Journal of Monetary Economics* 60 (3): 311–24.
- Angeloni, I., E. Faia, and M. Lo Duca. 2015. "Monetary Policy and Risk Taking." *Journal of Economic Dynamics and Control* 52 (March): 285–307.
- Aramonte, S., S. J. Lee, and V. Stebunovs. 2015. "Risk Taking and Low Longer-term Interest Rates: Evidence from the U.S. Syndicated Loan Market." Finance and Economics Discussion Series No. 2015-68, Board of Governors of the Federal Reserve System.

- Ayyagari, M., T. Beck, and M. S. M. Peria. 2018. "The Micro Impact of Macroprudential Policies: Firm-Level Evidence." IMF Working Paper No. 18/267.
- Bauer, M. D., and E. T. Swanson. 2020. "The Fed's Response to Economic News Explains the 'Fed Information Effect'." Working Paper No. 2020-06, Federal Reserve Bank of San Francisco.
- Becker, B., and V. Ivashina. 2015. "Reaching for Yield in the Bond Market." *Journal of Finance* 70 (5): 1863–1902.
- Bernanke, B. 2009. "Financial Reform to Address Systemic Risk." Speech given at the Council on Foreign Relations, Washington, DC, March 10.
- Borio, C., and H. Zhu. 2008. "Capital Regulation, Risk-taking and Monetary Policy: A Missing Link in the Transmission Mechanism?" BIS Working Paper No. 268.
- Brownlees, C., and R. F. Engle. 2017. "SRISK: A Conditional Capital Shortfall Measure of Systemic Risk." *Review of Financial Studies* 30 (1): 48–79.
- Bruno, V., and H. S. Shin. 2015. "Cross-Border Banking and Global Liquidity." *Review of Economic Studies* 82 (2): 535–64.
- Buch, C. M., S. Eickmeier, and E. Prieto. 2014a. "In Search for Yield? Survey-based Evidence on Bank Risk Taking." *Journal of Economic Dynamics and Control* 43 (June): 12–30.
- . 2014b. "Macroeconomic Factors and Microlevel Bank Behavior." *Journal of Money, Credit and Banking* 46 (4): 715–51.
- Caballero, R. J., and A. Simsek. 2013. "Fire Sales in a Model of Complexity." *Journal of Finance* 68 (6): 2549–87.
- Chow, G. C., and A.-I. Lin. 1971. "Best Linear Unbiased Interpolation, Distribution, and Extrapolation of Time Series by Related Series." *Review of Economics and Statistics* 53 (4): 372–75.
- Cieslak, A., and A. Schrimpf. 2019. "Non-monetary News in Central Bank Communication." *Journal of International Economics* 118 (May): 293–315.
- Coman, A., and S. P. Lloyd. 2019. "In the Face of Spillovers: Prudential Policies in Emerging Economies." Working Paper No. 2339, European Central Bank.
- Corsetti, G., J. B. Duarte, and S. Mann. 2018. "One Money, Many Markets — A Factor Model Approach to Monetary Policy in the Euro Area with High-Frequency Identification." Cambridge

- Working Paper in Economics No. 1816, Faculty of Economics, University of Cambridge.
- Dell’Ariccia, G., L. Laeven, and R. Marquez. 2014. “Real Interest Rates, Leverage, and Bank Risk-taking.” *Journal of Economic Theory* 149 (January): 65–99.
- Dell’Ariccia, G., L. Laeven, and G. A. Suarez. 2017. “Bank Leverage and Monetary Policy’s Risk-Taking Channel: Evidence from the United States.” *Journal of Finance* 72 (2): 613–54.
- European Central Bank. 2019. “The International Role of the Euro, June 2019.” ECB Report. <https://www.ecb.europa.eu/pub/ire/html/ecb.ire201906~f0da2b823e.en.htm>.
- Everett, M., J. de Haan, D.-J. Jansen, P. McQuade, and A. Samarina. 2019. “Mortgage Lending, Monetary Policy, and Prudential Measures in Small Euro-area Economies: Evidence from Ireland and the Netherlands.” DNB Working Paper No. 659.
- Gertler, M., and P. Karadi. 2015. “Monetary Policy Surprises, Credit Costs, and Economic Activity.” *American Economic Journal: Macroeconomics* 7 (1): 44–76.
- Gopinath, G., and J. Stein. 2018. “Trade Invoicing, Bank Funding, and Central Bank Reserve Holdings.” *AEA Papers and Proceedings* 108 (1, May): 542–46.
- Greenwood, R., A. Landier, and D. Thesmar. 2015. “Vulnerable Banks.” *Journal of Financial Economics* 115 (3): 471–85.
- Gürkaynak, R. S., B. Sack, and E. Swanson. 2005. “Do Actions Speak Louder Than Words? The Response of Asset Prices to Monetary Policy Actions and Statements.” *International Journal of Central Banking* 1 (1, May): 55–94.
- Hoesch, L., B. Rossi, and T. Sekhposyan. 2020. “Has the Information Channel of Monetary Policy Disappeared? Revisiting the Empirical Evidence.” Working Paper No. 2020-08, Federal Reserve Bank of San Francisco.
- Ioannidou, V., S. Ongena, and J.-L. Peydró. 2015. “Monetary Policy, Risk-Taking, and Pricing: Evidence from a Quasi-Natural Experiment.” *Review of Finance* 19 (1): 95–144.
- Jarocinski, M., and P. Karadi. 2020. “Deconstructing Monetary Policy Surprises — The Role of Information Shocks.” *American Economic Journal: Macroeconomics* 12 (2): 1–43.

- Jiménez, G., S. Ongena, J. Peydró, and J. Saurina. 2014. “Hazardous Times for Monetary Policy: What Do Twenty-Three Million Bank Loans Say About the Effects of Monetary Policy on Credit Risk-Taking?” *Econometrica* 82 (2): 463–505.
- Jordà, O. 2005. “Estimation and Inference of Impulse Responses by Local Projections.” *American Economic Review* 95 (1): 161–82.
- Kim, S., and A. Mehrotra. 2018. “Effects of Monetary and Macroprudential Policies—Evidence from Four Inflation Targeting Economies.” *Journal of Money, Credit and Banking* 50 (5): 967–92.
- . 2019. “Examining Macroprudential Policy and Its Macroeconomic Effects — Some New Evidence.” BIS Working Paper No. 825.
- Krippner, L. 2013. “Measuring the Stance of Monetary Policy in Zero Lower Bound Environments.” *Economics Letters* 118 (1): 135–38.
- Kuttner, K. N. 2001. “Monetary Policy Surprises and Interest Rates: Evidence from the Fed Funds Futures Market.” *Journal of Monetary Economics* 47 (3): 523–44.
- Martinez-Miera, D., and R. Repullo. 2017. “Search for Yield.” *Econometrica* 85 (2): 351–78.
- Melosi, L. 2017. “Signalling Effects of Monetary Policy.” *Review of Economic Studies* 84 (2): 853–84.
- Mertens, K., and M. O. Ravn. 2013. “The Dynamic Effects of Personal and Corporate Income Tax Changes in the United States.” *American Economic Review* 103 (4): 1212–47.
- Miranda-Agrippino, S., and H. Rey. 2020. “U.S. Monetary Policy and the Global Financial Cycle.” *Review of Economic Studies* 87 (6): 2754–76.
- Miranda-Agrippino, S., and G. Ricco. 2021. “The Transmission of Monetary Policy Shocks.” *American Economic Journal: Macroeconomics* 13 (3): 74–107.
- Nakamura, E., and J. Steinsson. 2018. “High-Frequency Identification of Monetary Non-Neutrality: The Information Effect.” *Quarterly Journal of Economics* 133 (3): 1283–1330.
- Neuenkirch, M., and M. Nöckel. 2018. “The Risk-taking Channel of Monetary Policy Transmission in the Euro Area.” *Journal of Banking and Finance* 93 (August): 71–91.

- Pesaran, M. H., and R. Smith. 1995. "Estimating Long-run Relationships from Dynamic Heterogeneous Panels." *Journal of Econometrics* 68 (1): 79–113.
- Piffer, M. 2016. "Notes on the Identification of VARs Using External Instruments." Mimeo.
- Rajan, R. G. 2005. "Has Financial Development Made the World Riskier?" NBER Working Paper No. 11728.
- Ramey, V. 2016. "Macroeconomic Shocks and Their Propagation." In *Handbook of Macroeconomics*, Vol. 2, ed. J. B. Taylor and H. Uhlig, 71–162 (chapter 2). Elsevier.
- Rey, H. 2015. "Dilemma Not Trilemma: The Global Financial Cycle and Monetary Policy Independence." NBER Working Paper No. 21162.
- Richter, B., M. Schularick, and I. Shim. 2019. "The Costs of Macroprudential Policy." *Journal of International Economics* 118 (May): 263–82.
- Schryder, S. D., and F. Opitz. 2019. "Macroprudential Policy and Its Impact on the Credit Cycle." Working Paper No. 19/990, Faculty of Economics and Business Administration, Ghent University, Belgium.
- Schularick, M., L. Ter Steege, and F. Ward. 2021. "Leaning Against the Wind and Crisis Risk." *American Economic Review: Insights* 3 (2): 199–214.
- Stock, J. H., and M. W. Watson. 2018. "Identification and Estimation of Dynamic Causal Effects in Macroeconomics Using External Instruments." *Economic Journal* 128 (610): 917–48.
- Towbin, P., and S. Weber. 2013. "Limits of Floating Exchange Rates: The Role of Foreign Currency Debt and Import Structure." *Journal of Development Economics* 101 (March): 179–94.
- Wu, J. C., and F. D. Xia. 2016. "Measuring the Macroeconomic Impact of Monetary Policy at the Zero Lower Bound." *Journal of Money, Credit and Banking* 48 (2–3): 253–91.