

Monetary Policy and Risk Taking*

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Abstract

We combine data evidence and model results to examine the transmission of monetary policy in presence of financial risks. The model includes banks (modelled as in Diamond and Rajan [23], [24]) and a financial accelerator (Bernanke et al. [11]). A monetary expansion increases bank leverage and risk; bank risk affects economic activity and prices. This risk-taking channel of monetary transmission modifies the effect stemming from the traditional financial accelerator mechanism. The model matches certain features of the data, as emerged in recent panel data studies and in our own time series estimates for the US and the euro area.

Keywords: monetary policy, bank behavior, leverage, financial accelerator.

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1 Introduction

Central banking no longer is what it used to be. Until 2007, central banks worldwide followed a well established paradigm, composed of three fundamental elements. The first – call it *single focus* – stipulated that monetary policy should aim solely at maintaining price stability, defined as a low and stable rate of change of the prices of a basket of consumer goods and services. The specific time horizon for achieving this target was debated, but most believed it should be rather short, around 18 to 24 months – inflation forecasts are notoriously unreliable at long horizons. The second tenet was that central banks should be *independent*, i.e. not influenced in their decisions by governments, businesses, trade unions, or other. The last element was a sort of *assignment* principle: central banks should not be distracted by concerns for other policy domains, nor should other policy actors share responsibility for price stability. For two reasons: first because shared objectives create uncertainty on where responsibilities really belong; second, because potential failures in attaining other goals may dent the credibility of central banks in achieving their primary objective, price stability. This latter argument was used most forcefully to suggest that central banks should not be responsible for banking and financial supervision¹. In the years of the "great moderation" the three legs of this paradigmatic tripod seemed so stable and solid that monetary policy was often referred to as a science.

The financial crisis raised questions on many of these earlier certainties. Revisited in light of the turmoil, the recent experience suggests that the transmission of monetary policy may be more complex than earlier assumed. Its effects may extend much beyond inflation and aggregate demand at short-medium horizons, to encompass the risk-taking propensity of economic agents, with second-round effects at longer and unknown lags. Naturally, the existence of a "risk-taking channel" of monetary policy – for which evidence has recently been provided, surveyed in this paper – would put the *single focus* tenet into question. But also the *assignment* argument would somehow be affected; if monetary policy can contribute

¹See the classic survey of Goodhart and Schoenmaker [27].

to the formation (or the mitigation) of systemic risks in the financial sector, and if the latter in turn feed back on macroeconomic performance with unknown lags, it is hard to escape the conclusion that monetary policy needs to keep financial stability implications into account, and that the macroeconomic implications of bank supervision and regulation need to be considered as well. Completing the triangle, though nobody has seriously questioned the merits of central banks *independence*, recent vibrations in certain political quarters – the US Congress, for example – reveal a temptation to attach to the assignment of new responsibilities to central banks in the area of financial stability a tighter scrutiny over their decisions².

In this complex picture, a key priority is to understand the linkages between monetary policy, financial risk and the business cycle. Our plan is the following. First, we briefly review the recent arguments and evidence on the risk taking channel of monetary policy. Second, we present some time series evidence on this channel in the US and the euro area. Third, we analyse a macro DSGE model with banks to interpret this evidence. The model is completely standard except that it combines a banking sector, based on the theory of Diamond and Rajan, and a traditional financial accelerator. In the model, firms use both internal and external funds (bank loans and corporate bonds) to finance investment. This flexible structure allows to examine the impact of monetary policy and other shocks on the lending and the funding behavior of banks, hence separately modelling the leverage of banks and firms. The results support the idea, corroborated by data evidence, that monetary policy influences risk-taking in the banking sector, and that risk in turn significantly influences output and price dynamics at longer lags. The model results, presented in comparison with the two simpler benchmarks (the model by Angeloni and Faia [8], henceforth AF, with banks but no financial accelerator, and the classic financial accelerator of Bernanke, Gertler and Gilchrist [11], without banks) help interpret certain salient features of the data.

The paper is organized as follows. In section 2 we start by describing some recently

²Kashyap and Mishkin [30].

published empirical evidence. In section 3 we present new time-series evidence on the transmission of monetary policy on financial risk in the US and the euro area. In section 4 we present our macro model. In section 5 we use the model to describe the impact of a few selected shocks, including specifically the effects of monetary policy on risk and the effect of risk on the rest of the economy. In doing so, we compare its properties with the two simpler benchmarks just mentioned. Finally, section 6 concludes.

2 Recent empirical evidence

The surge of interest for the implications of monetary policy on financial risks after the recent crisis contrasts sharply with the virtual absence of any reference to risk in the earlier literature on the monetary policy transmission mechanism. The classic 1995 survey by Mishkin, Taylor and others in the *Journal of Economic Perspectives* [33] does not mention risk except as a factor capable of reinforcing the strength of the financial accelerator. In the multi-country empirical study of monetary transmission in the euro area conducted by the Eurosystem central banks, dated 2003 (see Angeloni, Kashyap and Mojon [9]), indicators of bank risk were actually used in the econometric estimates of the “lending channel”, but only to quantify certain features of the banking sector that may affect the strength of the transmission, not because monetary policy may itself influence those characteristics, let alone for their financial stability implications.

In a different context, however, other papers had highlighted the potential importance of the link between monetary policy and financial risks well before the onset of the financial crisis. Already in 2000, Allen and Gale [5] had provided a theoretical underpinning for these ideas by showing how leveraged positions in asset markets create moral hazard: leveraged investors can back-stop losses by defaulting, and this makes asset prices deviate from fundamentals. The link with monetary policy, clarified in later work by Allen and Gale [6], consists in the fact that aggregate credit developments in the economy are, at least partly, under the control of monetary authorities. Borio and Lowe [18], described how asset market

bubbles, leading to financial risk and instability, can develop in a benign macroeconomic environment, including high growth, low inflation, low interest rates and accommodative monetary policy. Their seminal contribution was followed by a host of publications by the Bank for International Settlements calling for the adoption of a "macroprudential approach" to financial stability including, notably, a response of monetary policy to asset prices.

In 2005, Rajan [35] analysed how the incentives structures in the financial system may induce managers of banks and insurance companies to assume more risk under persistently low interest rates. In a low interest rate environment, portfolio managers compensated on the basis of nominal returns have an incentive to search for higher yields by taking on more risk. Risk built up during periods of monetary accommodation turns into instability when policy is tightened again, in the form of confidence crises and "sudden stops" of credit. Two are the implications for central banks: first, monetary policy should preemptively avoid prolonged periods of excessively low interest rates. Second, when high risk is already entrenched in the financial sector, abrupt policy tightening can be highly contractionary or even destabilising.

To help the empirical analysis, and also because their policy implications differ, its useful to distinguish between two different channels through which the risk-taking mechanism can operate. The first is via changes in the degree of riskiness of the intermediary's asset side. In presence of low and persistent interest rates levels, asset managers of banks and other investment pools have an incentive to shift the composition of their investments towards a riskier mix, for the reasons explained by Rajan. A second way in which more risk can be acquired is via the degree of leverage and the maturity of funding, affecting the risk of the bank balance sheet and of off-balance sheet structures implicitly linked to the mother institution. Risk-taking is stronger, other things equal, the shorter the maturity of borrowing. This channel operates in particular when short term rates are low and the yield curve upward sloping, an effect emphasised by Adrian and Shin [1]. While the two channels are conceptually distinct, it may be difficult to distinguish them since they tend to move together. Most available statistical and anecdotal information suggests that financial institutions on both sides of the

Atlantic (banks, conduits and SIVs, investment funds, insurance companies, etc.) became riskier, in the pre-crisis years, due to a mix of riskier investments and more fragile balance sheet structures.

The empirical evidence on these transmission mechanisms is limited. Two strands can be distinguished. A first one tries to identify effective leading indicators of financial crises. It has been noted that, in a variety of different national contexts and historical periods, financial crises tend to be preceded by a recurrent set of economic developments (see Reinhardt and Rogoff, [37]). In particular, using time series comprising data for 18 OECD countries between 1970 and 2007, Alessi and Detken [4] find that monetary and credit aggregates are leading indicators of costly asset price boom/bust cycles. A similar conclusion is reached by Goodhart and Hoffmann [26], focusing on house price booms. This evidence, though not immediately conclusive in establishing a causal link between monetary policy and risk-taking behavior, nonetheless suggest that variables that are close to the control span of monetary policy, such as monetary and credit aggregates, should be watched carefully since they are systematically associated with the insurgence of financial instability episodes.

Two very recent papers tackle the issue more directly and pertinently.

Maddaloni and Peydró Alcalde [32] use answers from a survey of lending behavior among banks of the euro area to see whether monetary policy influences the lending practices of banks. The survey responses allow, in principle, to identify a number of causal relations of interest. The Euro Area Bank Lending Survey, modelled on the Fed's Loan Officer Survey, consists in a list of 18 questions asked every quarter to a sample of (as of today) about 120 banks. The first and pivotal question reads as follows: "*Over the past three months, how have your bank's credit standards, as applied to the approval of loans or credit lines to enterprises, changed?*". The remaining questions extend and qualify the first, examining also consumer and mortgage loans and investigating the reasons for any changes in the standards. Three groups of reasons for changing the "standards" are singled out: 1) Costs of funds and balance sheet constraints; 2) Pressure from competition; 3) Perception of risk. The

first group can broadly be identified as supply related, as it signals that standards change because of bank-specific conditions; the third is related to demand, since it depends upon borrowers' conditions, while the second is more difficult to classify.

The authors use a panel regression to link the survey results, expressed as net balances of positive and negative answers, to alternative indicators of monetary policy. The proxy of policy tightness has consistently significant effects and negative coefficients, for corporate as well as personal loans, and for reasons that are connected to the first group of motives, namely the banks' cost of funds and balance sheet constraints. Moreover, the longer a given policy stance lasts, the more effect seems to have on credit standards.

These results, interesting and suggestive in themselves, also highlight an ambiguity in interpreting the link between monetary policy and lending behavior that extends to other contexts as well. The fact that a monetary expansion determines less strict credit "standards" by banks may or may not have implications for risk. Optimizing banks receiving more liquidity from the central bank and facing lower opportunity costs will naturally move down the expected loan return schedule, in fact typically lowering their lending rates. Though they probably interpret it as softening of "credit standards", this does not necessarily increase lending risk. Even if some more risky borrowers happen to be financed, this may still be efficient and remain within acceptable safety bounds. So, a positive answer to the question above does not necessarily imply that a monetary expansion has an undesirable impact on bank risk. Conversely, even if the answer is negative, this does not mean that bank risk may not be increasing, perhaps excessively, in other ways. Asset quality is only one of the ways financial intermediaries use to take on more risk; leverage and maturity mismatch are other, probably more important channels.

Another recent paper (Altunbas et al. [7]) uses a more comprehensive sample and a different measure of bank risk. They consider over 600 listed European banks, in 16 countries, for which Moody's KMV has computed expected default frequencies (EDF hereafter). EDFs, expressing market perceptions of the default probability at a given time horizon, are a widely

used measure of bank risk, shown to have predictive power in many cases. EDFs are obtained translating, with a model, several market and balance sheet indicators into a single measure, a time-varying probability of default at a specific time horizon. The authors make this the dependent variable in a panel regression, that includes a variety of explanatory factors – macroeconomic variables, market data, other bank characteristics – as well as monetary policy. The results suggest that an increase of short term rates decreases bank risk on impact but increases it over time. This is interpreted as the combination of two effects: in the short run, an increase in rates lowers the risk of outstanding loans; over time, the higher level of rates induces hazardous lending behavior, leading to more risk. A similar conclusion is reached by Jimenez et al. [29] in their analysis of a large sample of Spanish banks, using more detailed credit register data.

The estimates of Altunbas et al. [7] have the advantage of having direct implications for bank risk, but, given the very general nature of the risk measure employed, they do not allow to distinguish among different transmission channels. To do this, we explore time series evidence (see next section). Importantly, using VAR analysis allows us also to account for the endogenous response of monetary policy to bank risk taking, something neglected in the previously mentioned panel data evidence.

Our paper bears some relation to a recent literature which builds banking model to explore the extent of the risk taking channel (see Acharya and Naqvi [2], Agur and Demertzis [3], Dell’Ariccia, Laeven and Marquez [31], De Nicolo’ [22]). Those authors focus on the risk taking channel on the investment side of the banks’ balance sheet, while we explore the channel on both sides of the balance sheet. Most importantly, the above mentioned papers use static (partial equilibrium) banking model in which the policy rate is an exogenous variables, while we analyze the risk taking channel within a dynamic general equilibrium model with banking: the dynamic general equilibrium setting allows us to account for the feedback from banks’ optimal choices to policy rates.

3 Some time series evidence

Table 1 presents Granger causality tests of the relationship between monetary policy (measured by a de-trended nominal policy rate) and different indicators of bank risk. The column labelled “Equation” specifies the dependent variable, that labelled “Excluded” indicates the variable whose exclusion is being tested; the p-value of the test is reported in the last column.

Our data definitions are given in Appendix A at the end of the paper. In essence we use two definitions of risk, one expressing funding risk (in two variants) and the other measuring the riskiness of the asset mix (in four variants)³. We proxy funding risk with the ratio of total bank assets to deposits: this is a good measure particularly in the years leading to the crisis, when retail deposits were characterised by high stability and long duration relative to other uninsured short term funds (ABCPs, repos). A rising ratio means that banks were making increasing use of volatile sources of funds. The two variants are a 12-month change of the ratio and a detrended ratio of the levels. Asset risk is measured by the incidence of household credit (consumer credit and mortgage) on the asset side. The four variants experiment with detrended ratios vs. 12-month changes, and also excluding treasury bonds from the definition of total assets.

In the estimates for the US (Panel A), we find evidence of causality from monetary policy to the different measures of risk, while causality in the other direction is not detected. For the euro area, the causal relation from monetary policy to bank risk is also detected, but the evidence is weaker than for the US. Conversely, in the euro area causality seems to run also in the other direction, from risk to monetary policy.

We then consider VAR models, also incorporating macro variables. We focus on the effect of monetary policy on risk and the effect of risk on the business cycle, an aspect emphasised by Bloom[15] and Bloom et al. [16], and we again compare the euro area and the US. In addition to the indicators we already discussed, we also include an option-based

³We also experimented with formal definitions of leverage, but our attempts were not successful, possibly because data on capital are not consistently reliable and not comparable across countries.

stock market volatility index, RISK1, constructed as a binary variable changing value when the index adjusts beyond a given threshold (see Appendix A for details). Bloom [15] shows that the stock market volatility is a good general proxy of corporate sector risk, highly correlated with the variability or dispersion of corporate returns. RISK2 is one of the proxies we considered already for the riskiness of the bank asset-mix, while RISK3 is one of our measures of bank funding risk.

We use monthly data and estimate standard orthogonalized VARs impulse responses on the following variables (in the estimation order): industrial production, employment, inflation, funding risk (RISK3), asset risk (RISK2), monetary policy, stock market volatility (RISK1) and the stock market index. Including the stock-market levels as the last variable in the VAR ensures that the impact of stock market levels is already controlled for when looking at the impact of volatility shocks. The ordering is based on the assumption that all shocks instantaneously influence the stock market, both in terms of levels and volatilities, and the interest rate. Subsequently bank balance sheet variables adjust, followed by prices and quantities. As it is not clear which of our bank risk variables should be placed first, we estimated different VAR models inverting the order of these two variables; the results are not affected.

Chart 1 shows the transmission of a monetary policy shock to inflation, output and employment. In each chart the left column refers to the US, the right one refers to the euro area. The results are qualitatively similar to other results in the monetary policy transmission literature. A monetary policy shock has, after a short positive impact, a persistent negative effect on US inflation; in the euro area the negative effect is more rapid and strong, but it vanishes after a few months. The effects on US output and employment are negative, very significant and long lasting. The euro area effects are similar but slightly less strong and significant. This may be due to the fact that the euro area time series are much shorter.

Chart 2 shows the effect of a shock in uncertainty (RISK1) on inflation, output and employment. The chart confirms the results of Bloom et al. [16], showing that an increase

in uncertainty (RISK1) has a significant negative short term effect on inflation, output and employment in the US. In the euro area the effects are not significant with the exception of the negative initial impact on inflation⁴.

Finally, chart 3 shows the impulse responses of a monetary policy shock on the three measures of risk. A monetary policy restriction tends to have a negative effect on risk, but its strength, profile and significance depends on the risk measure used and differs in the US relative to the euro area. The reduction of RISK3 is significant only in the US. The effect on RISK2 is significant, delayed and persistent in both areas; note that the impact effect is close to nil or even positive, while the negative effect builds up gradually over time. Finally, the effects on the stock market volatility measure are insignificant⁵.

We finally conducted a series of robustness checks on our results. We first changed the definition and the measurement of our three risk variables, replacing them with the alternative variables listed in Appendix A. For the US the results are stable, only the proxy for the asset-mix risk turns insignificant in a few of the specifications. The impact of monetary policy on funding risk is very robust. For the euro area, the results are less stable. Finally, we ran the estimates on quarterly data; the results are robust for the US – for the euro area, the time series are too short to be reliable.

⁴To check the robustness of the results for the euro area, we estimated the model using implied volatility instead of the binary indicator of Bloom. The results for the euro area are substantially the same and the reaction of the macro variables to a shock to uncertainty is at best weakly significant. One reason for the lack of significance could be that the series for the euro area are too short. We therefore exclude from the model the variables RISK2 and RISK3 that are available only since the end of the 90s and we re-estimated the model with data since 1990 using only with the macro variables and RISK1 (or the implied volatility). In this specification, RISK1 is again weakly significant while when the implied volatility is used, it has a strong negative and significant initial impact on inflation, a slight and significant negative impact on industrial production and no impact on employment.

⁵The implied volatility that we use as measure of overall uncertainty and corporate risk as suggested by Bloom, can be decomposed into a component that reflects actual expected stock market volatility (uncertainty) and a residual (the so-called variance premium) that reflects risk aversion and other non-linear pricing effects (see Bekaert, Hoerova and Scheicher [13]). In a related paper, Bekaert Hoerova and Lo Duca [12] investigate the separate impact of monetary policy on the two components of implied volatility using SVAR. They find that the monetary policy shock for the US has a positive impact on risk aversion while it does not affect the component related to uncertainty.

4 A macroeconomic model with banks

The real sector of the model consists in a conventional DSGE model with nominal rigidities. On the financial side our framework is richer, featuring banks with an endogenously modelled funding choice and endogenous risk of bank run. The lending side of the bank follows a standard financial accelerator model. This structure allows to consider the role played in monetary transmission by the two distinct sources of risk, respectively on the funding side and on the lending side of the bank.

4.1 Households

There is a continuum of identical households who consume, save and work. In every period, a fraction γ of the households members are workers/depositors, a fraction φ are entrepreneurs who invest in capital and a fraction $1 - \gamma - \varphi$ are bank capitalists. As worker, the household can work either in the production sector or as employee in the banking sector. Bank capitalists remain engaged in their business activity next period with a probability θ , independent of history, while entrepreneurs remain in business with a probability ς . This finite survival scheme is needed to avoid that bank capitalists and entrepreneurs accumulate enough wealth to remove the limited liability constraint. A fraction $(1 - \theta)$ of bank capitalists exit in every period, while a fraction $(1 - \varsigma)$ of entrepreneurs exit in every period. To maintain the share of bank capitalists and entrepreneurs constant over time, we assume that in every period a fraction $(1 - \theta)$ of workers become bank capitalists and a fraction $(1 - \varsigma)$ of workers become entrepreneurs. Households invest in deposits and corporate bonds⁶ with intermediaries that they do not own. Deposits, D_t , pay a gross nominal return R_t one period later. In fact due to the possibility of bank runs, the return on deposits is subject to a time-varying risk (see Appendix 1). However, we assume that expected losses are largely covered by government intervention and are financed with lump sum taxations: hence the loss in case

⁶Corporate bonds have the same rate of return of deposits, for simplicity. Hence, based on the Harrison and Kreps [28] equivalence results we can omit corporate bonds from the budget constraint as their return can be expressed as a linear transformation of returns on demand deposits.

of default affects the resource constraint but not the households' budget constraint⁷. Bank capitalists and entrepreneurs accumulate wealth in every period using the proceeds from their investment activity: we assume that such proceeds are reinvested entirely. Workers in the production sector receive an hourly nominal wage W_t , while workers in the financial industry (bank managers) receive for their services a time-varying fee, Ξ_t ⁸.

Households maximize the following discounted sum of utilities:

$$E_0 \sum_{t=0}^{\infty} \beta^t U(C_t, N_t) \quad (1)$$

where C_t denotes aggregate consumption and N_t denotes labour hours.

Households are the owners of the monopolistic competitive sector, hence they receive Θ_t in nominal profits in each period. The budget constraint reads as follows:

$$P_t C_t + T_t + D_{t+1} \leq W_t N_t + \Theta_t + \Xi_t + R_t D_t \quad (2)$$

where T_t is lump sum taxation. Households choose the set of processes $\{C_t, N_t\}_{t=0}^{\infty}$ and assets $\{D_{t+1}\}_{t=0}^{\infty}$, taking as given the set of processes $\{P_t, W_t, R_t\}_{t=0}^{\infty}$ and the initial wealth D_0 so as to maximize 1 subject to 2. The following optimality conditions hold:

$$\frac{W_t}{P_t} = -\frac{U_{n,t}}{U_{c,t}} \quad (3)$$

$$U_{c,t} = \beta E_t \{R_t U_{c,t+1}\} \quad (4)$$

Equation 3 gives the optimal choice for labour supply. Equation 4 gives the Euler condition with respect to demand deposits. Optimality requires that the first order conditions and No-Ponzi game conditions are simultaneously satisfied.

⁷To preserve the possibility of bank runs, it is sufficient that deposit risk is not covered fully.

⁸This fee is already inclusive of the fraction of workers in the banking sector. As the latter is very small, fluctuations in the fee are negligible.

4.2 Banks

A brief sketch of the structure of financial intermediation is as follows. Entrepreneurs launch investment projects whose return is subject to idiosyncratic shocks. Projects are financed partly by bank loans, partly by entrepreneurs' net worth and partly by corporate bonds. If the return on the investment project (a stochastic variable) is insufficient to reimburse the bank loan, inclusive of its contractual return, the firm fails and the project is appropriated by the bank.

Within the bank, lending and fund-raising are administered separately, say by a credit department and a funding department, linked together by an internal contract. The lending department receives funds from the funding department and uses them to enter into credit contracts with entrepreneurs. Through its funding department, the bank raises funds from depositors and bank capitalists. Importantly, deposits are not traditional retail deposits covered by deposit insurance, but risky short term funding instruments, such as asset-backed short term securities or short term repos, yielding a noncontingent return and subject to run whenever the bank is perceived as potentially unable to pay depositors in full. Bank capitalists claim the residual value after depositors are paid out. The bank capital structure is determined by bank managers, acting on behalf of depositors and capitalists by maximizing their overall return. Due to its skills as relationship lender, the bank extracts rents that are rebated back to bank capitalists, as they bear the liability risk. Likewise, if the return to the bank is insufficient to pay out depositors, there is a run on the bank, in which case the bank capital holders get zero while depositors get the market value of the liquidated loan⁹.

Notice that there is risk on both sides of the bank, due to the possibility of run on deposits as well as the idiosyncratic shocks to investment returns. Hence to understand how the transmission through banks works one needs to analyse the impact shocks on both sides

⁹The contractual agreement between banks and depositors is incentive compatible, implying that the bank is willing to declare the true realized return on assets: the threat of bank runs, indeed, works as truth revealing mechanism, providing a discipline device. As pointed out in Diamond and Rajan [24] in this context deposit insurance is inefficient as it distorts banks' incentives.

of banks' balance sheet.

4.2.1 Bank Lending

The credit side is modelled as a standard financial accelerator (Bernanke et al. [11], Faia and Monacelli [25]), hence we can describe it briefly here (see Appendix 2 for details). The investment projects financed by the bank are characterized by an expected return equal to $R_{t+1}^K Q_t K_{t+1}$, where R_{t+1}^K , Q_t and K_{t+1} are respectively the nominal return on capital, the price of capital and real capital. Project outcomes are subject to idiosyncratic uncertainty, taking the form of a multiplicative random shock applied to productivity, assumed to have a uniform density function.

The contract between the firm and the lending department stipulates ex-ante a fixed gross return for the bank R_{t+1}^{BF} and a financing amount $EF_{t+1} = Q_t K_{t+1} - NW_{t+1}$, where NW_{t+1} is the entrepreneur's net worth. EF_{t+1} includes a fixed proportion $1 - \xi$ of own bank funds, L_{t+1} , while the rest is raised by issuing corporate bonds. Ex-post there are two cases. If the firm doesn't default, it pays back the debt, inclusive of the contractual return R_{t+1}^{BF} , and the entrepreneur retains any surplus. If not, the firm goes bankrupt and the lending department liquidates the project. In this case, the lender has to bear a monitoring cost equal to a fraction μ of the project value.

The bank gets an average return R_t^A from its financing. The remaining part of the project is financed through corporate debt sold to households, at a cost equal to the deposits rate R_t . Working out the analytics as in Faia and Monacelli [25], one obtains an expression for the *premium on external finance*, $\rho(\varpi_{t+1})$, as follows

$$\rho(\varpi_{t+1}) = \frac{R_{t+1}^K}{[(1 - \xi)R_t^A + \xi R_t]} = h(\varpi_{t+1}) \left(1 - \frac{NW_{t+1}}{Q_t K_{t+1}} \right) \quad (5)$$

where ϖ_{t+1} and μ are respectively the bankruptcy threshold and the cost of bank monitoring in the financial accelerator model. One can easily show that $h'(\bullet) > 0$. This expression suggests that the external finance premium is an equilibrium inverse function of the aggregate financial conditions in the economy, expressed by the (inverse) leverage ratio $\frac{NW_{t+1}}{Q_t K_{t+1}}$.

4.2.2 Bank Funding

The liability side of the bank is modeled as in Angeloni and Faia [8]. Total bank funds are equal to the sum of deposits (D_t) and bank capital, (BK_t):

$$L_t = (1 - \xi)(Q_t K_{t+1} - NW_t) = D_t + BK_t \quad (6)$$

The funding department determines the capital structure (shares of deposits and capital) on behalf of depositors and bank capitalists. Following Diamond and Rajan ([23], [24]), we assume the bank manager maximizes the combined expected return of depositors and bank capitalists, in exchange for a fee.

The timing is as follows. At time t , the banker decides the optimal capital structure, expressed by the ratio of deposits to the total cost of the project, d_t , collects the funds, and transfers the funds to the lending department. At time $t+1$, the project's outcome is revealed, the contractual return R_t^A is transferred from the lending to the funding department, as discussed below, and payments to depositors and capitalists are made. A new round of projects starts.

The credit and the funding departments are tied by a contract that stipulates that the former pays to the latter a return on the funds received R_t^A , equal to its expected return on assets. Moreover, we assume that the return on assets for the funding department is subject to an idiosyncratic shock x_t with a uniform distribution defined in the space $\{-h; h\}$ and with a standard decreasing hazard function¹⁰. Again, individual subscripts are omitted for simplicity: the linearity of the problem allows easy aggregation. We can think of x_t as a liquidity shock, due for example to a dry up in the interbank market. Each period the realized return $R_t^A + x_t$ is split between the depositors, the bank capitalists and the funding department itself, that earns a fee for its liability management service. If the cash flow accruing to the funding department is insufficient to reimburse the depositors, including the

¹⁰In Angeloni and Faia [8] we show that results are unchanged also when assuming a logistic or a normal distribution. The uniform distribution is chosen as benchmark as it allows for analytical solution of the deposit ratio, therefore allows us to gain intuition of the main mechanisms at work.

non-contingent return on deposits, R_t , there is a run on the bank, which forces an early liquidation of the loan by the credit department.

We assume the bank is a *relationship lender*: by lending, the credit department acquires a specialized non-sellable knowledge of the characteristics of the project that determines an advantage in extracting value from it before the project is concluded, relative to other agents. Let the ratio of the value for the outsider, namely the liquidation value, to the value for the bank be $0 < \lambda < 1$. Even if the value is extracted by the bank, hence without loss of relationship knowledge, a bank run may entail a specific cost $1 > c \geq 0$; when a run occurs, the liquidation value of the project extracted by the bank loses a constant fraction c . Such cost, can be interpreted as arising from early liquidation of projects.

Consider the payoffs to each of our players, namely the depositor, the bank capitalist and the bank, as liability manager. There are three cases.

Case A: Run for sure. The return is too low to pay depositors; $R_t^A + x_t < R_t d_t$. Payoffs in case of run are distributed as follows. Capitalists receive the leftover after depositors are served, so they get zero in this case. Depositors, in absence of bank intervention, would get only a fraction $\lambda(1-c)(R_t^A + x_t)$ of the project's outcome. The remainder $(1-\lambda)(1-c)(R_t^A + x_t)$ is split in half between depositors and the bank¹¹. Therefore, depositors get

$$\frac{(1 + \lambda)(1 - c)(R_t^A + x_t)}{2} \quad (7)$$

and the bank

$$\frac{(1 - \lambda)(1 - c)(R_t^A + x_t)}{2} \quad (8)$$

Case B: Run only without the bank. The return is high enough to allow depositors to be served if the project's value is extracted by the bank, but not otherwise; i.e $\lambda(v + x_t) < R_t d_t \leq (R_t^A + x_t)$. In this case, the capitalists alone cannot avoid the run, but with the bank

¹¹In Angeloni and Faia [8] we show that different bargaining share between outside investors and bank managers would not affect the results. The equal split is chosen for analytical simplicity.

they can. So depositors are paid in full, $R_t d_t$, and the remainder is split in half between the banker and the capitalists, each getting $\frac{R_t^A + x_t - R_t d_t}{2}$. Total payment to outsiders is $\frac{R_t^A + x_t + R_t d_t}{2}$.

Case C: No run for sure. The return is high enough to allow all depositors to be served, with or without the bank's participation. This happens if $R_t d_t \leq \lambda(R_t^A + x_t)$. Depositors get $R_t d_t$. However, unlike in the previous case, now the capitalists have a higher bargaining power because they could decide to liquidate the project alone and pay the depositors in full, getting $\lambda(R_t^A + x_t) - R_t d_t$. This provides thus a lower threshold for them. The banker can extract $(R_t^A + x_t) - R_t d_t$, and again we assume that the capitalist and the bank split this extra return in half. Therefore, the bank gets:

$$\frac{\{[(R_t^A + x_t) - R_t d_t] - [\lambda(R_t^A + x_t) - R_t d_t]\}}{2} = \frac{(R_t^A - \lambda)(1 + x_t)}{2}$$

This is less than what the capitalist gets. Total payment to outsiders is:

$$\frac{(1 + \lambda)(R_t^A + x_t)}{2}$$

The expected value of total payments to outsiders as follows:

$$\begin{aligned} & \frac{1}{2h} \int_{-h}^{R_t d_t - R_t^A} \frac{(1 + \lambda)(1 - c)(R_t^A + x_t)}{2} dx_{j,t} + \frac{1}{2h} \int_{R_t d_t - R_t^A}^{\frac{R_t d_t}{\lambda} - R_t^A} \frac{(R_t^A + x_t) + R_t d_t}{2} dx_{j,t} + \quad (9) \\ & + \frac{1}{2h} \int_{\frac{R_t d_t}{\lambda} - R_t^A}^h \frac{(1 + \lambda)(R_t^A + x_t)}{2} dx_{j,t} \end{aligned}$$

The three terms express the payoffs to outsiders in the three cases described above, in order. The banker's problem is to maximise expected total payments to outsiders by choosing the suitable value of d_t .

It can be shown (see [8] for details) that the value of d_t that maximises equation 9 is comprised in the interval $\lambda \frac{R_t^A + h}{R_t} < d_t < \frac{R_t^A + h}{R_t}$. In this zone, the third integral in the equation vanishes and the expression reduces to

$$\frac{1}{2h} \int_{-h}^{R_t d_t - R_t^A} \frac{(1+\lambda)(1-c)(R_t^A + x_t)}{2} dx_{j,t} + \frac{1}{2h} \int_{R_t d_t - R_t^A}^h \frac{(R_t^A + x_t) + R_t d_t}{2} dx_{j,t} \quad (10)$$

The above function is a piece-wise concave function. Differentiating and solving for d_t yields the following equilibrium condition:

$$d_t = \frac{1}{R_t} \frac{R_t^A + h}{2 - \lambda + c(1 + \lambda)} \quad (11)$$

Since the second derivative is negative, this is the optimal value of d_t . Given the size of the project financed, $Q_t L_t$, the above equation implies an aggregate bank capital:

$$BK_t = \left(1 - \frac{1}{R_t} \frac{R_{A,t} + h}{2 - \lambda + c(1 + \lambda)}\right) Q_t L_t \quad (12)$$

Bank Capital Accumulation After remunerating depositors and paying the competitive fee to the banker, a return accrues to the bank capitalist as retained earning (including any reinvested dividends). Bank capital accumulates from retained earnings as follows:

$$BK_{t+1} = \frac{\theta}{\pi_t} [BK_t + R_{t+1}^{BK} (1 - \xi)(Q_{t-1} K_t - NW_t)] \quad (13)$$

where R_{t+1}^{BK} is the unitary return to the capitalist. The parameter θ is the bank survival rate, which by law of large number equalizes the ratio of bank capitalists present in the economy in each periods. R_{t+1}^{BK} can be derived from equation 10 as follows:

$$R_{t+1}^{BK} = \frac{1}{2h} \int_{R_{t+1} d_{t+1} - R_{A,t+1}}^h \frac{(R_{t+1}^A + x_{j,t+1}) - R_{t+1} d_{t+1}}{2} dx_{j,t+1} = \frac{(R_{t+1}^A + h - R_{t+1} d_{t+1})^2}{8h} \quad (14)$$

Note that this expression considers only the no-run state because if a run occurs the capitalist receives no return. The accumulation of bank capital obtained substituting 14 into 13:

$$BK_{t+1} = \theta [BK_t + \frac{(R_{t+1}^A + h - R_{t+1} d_{t+1})^2}{8h} (1 - \xi)(Q_{t-1} K_t - NW_t)] \quad (15)$$

The cyclical behavior of the bank capital structure is quite complex, depending on several counterbalancing factors. To gain intuition, we can interpret equation 12 as a demand for bank capital given the volume of loans L_t and the interest rate structure (R_t, R_t^A) , while equation 15 can be interpreted as the supply of bank capital in each sub-sequent period.

4.2.3 Balance Sheet and Risk Taking Channels

The structure of the banking sector gives rise to two distinct channels of monetary policy: a balance sheet and a risk taking channel. The first, originating from the bank lending side, is a traditional financial accelerator: a fall in the short term interest rate increases the value of collateral in the firm's balance sheet and results in a decline in the external finance premium (EFP), which boosts investment beyond the level obtained in absence of credit frictions. Under a monetary policy shock this premium is *countercyclical*, in the sense that a decline in the premium is accompanied by an expansion of investment and output. The expression of this premium is given by equation 5.

The second channel, originating instead from the bank funding side, arises because changes in short term rates affect bank bank leverage and risk. Looking at equation 11

$$d_t = \frac{1}{R_t} \frac{R_t^A + h}{2 - \lambda + c(1 + \lambda)}$$

we can see that a decline in R_t has a *ceteris paribus* equiproportional inverse effect on d_t ; however d_t is also subject to further changes as a result of adjustments in R_t^A taking place in general equilibrium. We can define a corresponding "bank lending premium" (BLP) from equation 11 in the following form:

$$\frac{R_t^A}{R_t} = d_t[2 - \lambda + c(1 + \lambda)] - \frac{h}{R_t} = \alpha d_t - \frac{h}{R_t} \quad (16)$$

where $\alpha = 2 - \lambda + c(1 + \lambda)$. In equation 16 there is no unambiguous relation between d_t and $\frac{R_t^A}{R_t}$, because R_t also appears on the right hand side, but some intuition can be gauged if one considers parameter values. For our parameters (see a later section), $h \simeq 0.5$ and $\alpha \simeq 2$. Considering again a decline in R_t and a *ceteris paribus* equiproportional inverse effect on d_t ,

we note that, being the numerical values of R_t and d_t in our parametrisation relative close to one another (the first slightly below unity, the second slightly above), the direction of change in the RHS of 16 tends to be positive. Hence, a decline in R_t likely leads to an increase in the BLP. Note that BLP, unlike EFP, is *pro-cyclical* under this shock, hence the presence of both transmission channels may lead to complex dynamic interactions.

The degree of bank risk in our model is measured by the probability of a bank run occurring. This probability is equal to:

$$\frac{1}{2h} \int_{-h}^{R_t - R_t^A} dx_{j,t} = \frac{1}{2} \left(1 - \frac{R_t^A - R_t d_t}{h} \right) \quad (17)$$

Again, for our parameter values, bank risk is likely to increase after a decline in R_t . Intuitively, if $R_t d_t$ remains roughly constant on impact and BLP rises, then R_t^A is likely to decline rise less than R_t . Hence, for plausible parameter values bank risk should increase following a monetary expansion – though of course, this and the preceding intuitions can rigorously be checked only by a formal dynamic equilibrium analysis.

4.3 Producers

One important reason for introducing sticky prices in our model is the necessity to have non-neutral effects of monetary policy. As our main goal is to analyze the monetary transmission mechanism in its various aspects, non-neutrality is an essential starting point. It is, however, equally true that the risk taking channel highlighted above would alone suffice to induce real effects of changes in the policy rates. However, the sole risk taking channel might result, for some configuration of the parameters, in the unpleasant outcome that a reduction in the policy rate might be contractionary. This provides a further justification for introducing sticky prices as, this form of monetary non-neutrality, guarantees expansionary effects of interest rate reduction at least in the short run, an outcome, the latter, consistent with empirical evidence.

We introduce sticky price by assuming quadratic adjustment costs on prices. Each firm

i has monopolistic power in the production of its own variety and therefore has leverage in setting the price. In changing prices it faces a quadratic cost equal to $\frac{\vartheta}{2}(\frac{P_t(i)}{P_{t-1}(i)} - 1)^2$, where $\pi = 1$ is the *steady state* inflation rate and where the parameter ϑ measures the degree of nominal price rigidity. The higher ϑ the more sluggish is the adjustment of nominal prices. In the particular case of $\vartheta = 0$, prices are flexible. Each firm assembles labour (supplied by the workers) and (finished) entrepreneurial capital to operate a constant return to scale production function for the variety i of the intermediate good:

$$Y_t(i) = A_t F(N_t(i), K_t(i)) \quad (18)$$

Each monopolistic firm chooses a sequence $\{K_t(i), L_t(i), P_t(i)\}$, taking nominal wage rates W_t and the rental rate of capital Z_t , as given, in order to maximize expected discounted nominal profits:

$$E_0 \left\{ \sum_{t=0}^{\infty} \Lambda_{0,t} [P_t(i) Y_t(i) - (W_t N_t(i) + Z_t K_t(i)) - \frac{\vartheta}{2} \left[\frac{P_t(i)}{P_{t-1}(i)} - \pi \right]^2 P_t] \right\} \quad (19)$$

subject to the constraint $A_t F_t(\bullet) \leq Y_t(i)$, where $\Lambda_{0,t}$ is the households' stochastic discount factor.

Let's denote by $\{mc_t\}_{t=0}^{\infty}$ the sequence of Lagrange multipliers on the above demand constraint, and by $\tilde{p}_t \equiv \frac{P_t(i)}{P_t}$ the relative price of variety i . The first order conditions of the above problem read:

$$\frac{W_t}{P_t(i)} = mc_t A_t F_{n,t} \quad (20)$$

$$\frac{Z_t}{P_t(i)} = mc_t A_t F_{k,t} \quad (21)$$

$$\begin{aligned} 0 = & Y_t \tilde{p}_t^{-\varepsilon} ((1 - \varepsilon) + \varepsilon mc_t - \vartheta \left[\pi_t \frac{\tilde{p}_t}{\tilde{p}_{t-1}} - 1 \right] \frac{\pi_t}{\tilde{p}_{t-1}} + \\ & + \vartheta E_t \left\{ \left[\pi_{t+1} \frac{p_{t+1}}{p_t} - 1 \right] \pi_{t+1} \frac{\tilde{p}_{t+1}}{\tilde{p}_t^2} \right\} \end{aligned} \quad (22)$$

where $F_{n,t}$ is the marginal product of labour, $F_{k,t}$ the marginal product of capital and $\pi_t = \frac{P_t}{P_{t-1}}$ is the gross aggregate inflation rate. Notice that all firms employ an identical capital/labour ratio in equilibrium, so individual prices are all equal in equilibrium. The Lagrange multiplier mc_t plays the role of the real marginal cost of production. In a symmetric equilibrium $\tilde{p}_t = 1$. This allows to rewrite equation 22 in the following form:

$$U_{c,t}(\pi_t - 1)\pi_t = \beta E_t\{U_{c,t+1}(\pi_{t+1} - 1)\pi_{t+1}\} + U_{c,t}A_tF_t(\bullet)\frac{\varepsilon}{\vartheta}(mc_t - \frac{\varepsilon - 1}{\varepsilon}) \quad (23)$$

The above equation is a non-linear forward looking New-Keynesian Phillips curve, in which deviations of the real marginal cost from its desired steady state value are the driving force of inflation.

4.3.1 Capital Producers

Adjustment costs on capital are introduced to introduce time-varying price of capital. A competitive sector of capital producers combine investment, expressed in the same composite as the final good, hence with price P_t , and existing capital stock to produce new capital goods. This activity entails physical adjustment costs. The corresponding CRS production function is $\phi(\frac{I_t}{K_t})K_t$, so that capital accumulation obeys:

$$K_{t+1} = (1 - \delta)K_t + \phi(\frac{I_t}{K_t})K_t \quad (24)$$

where $\phi(\bullet)$ is increasing and convex.

Define Q_t as the re-sell price of the capital good. Capital producers maximize profits $Q_t\phi(\frac{I_t}{K_t})K_t - P_tI_t$, implying the following first order condition:

$$Q_t\phi'(\frac{I_t}{K_t}) = P_t \quad (25)$$

The gross (nominal) return from holding one unit of capital between t and $t + 1$ is composed of the rental rate plus the re-sell price of capital (net of depreciation and physical adjustment costs):

$$Y_t^k \equiv Z_t + Q_t \left((1 - \delta) - \phi' \left(\frac{I_t}{K_t} \right) \frac{I_t}{K_t} + \phi \left(\frac{I_t}{K_t} \right) \right) \quad (26)$$

The gross (real) return to entrepreneurs from holding a unit of capital between t and $t + 1$ is equalized in equilibrium to the gross (real) return that entrepreneurs return to banks for their loan services, R_{t+1}^K :

$$\frac{R_{t+1}^K}{\pi_{t+1}} \equiv \frac{Y_{t+1}^k}{Q_t} \quad (27)$$

4.4 Official Sector and Market Clearing

We assume that monetary policy is conducted by means of an interest rate reaction function of this form:

$$\ln \left(\frac{1 + R_t}{1 + R} \right) = (1 - \phi_r) \left[\phi_\pi \ln \left(\frac{\pi_t}{\pi} \right) + \phi_y \ln \left(\frac{Y_t}{Y} \right) \right] + \phi_r \ln \left(\frac{1 + R_{t-1}}{1 + R} \right) \quad (28)$$

All variables are deviations from the target or steady state (symbols without time subscript).

The government runs a balance budget and uses lump sum taxation to finance exogenous government expenditure and to cover the average losses to households in case bank runs occur:

$$T_t = G_t + \Delta_t$$

where $\Delta_t = \left(Rd - \frac{(1+\lambda)R_A}{2} \right) \frac{1}{2h} \int_{-h}^{Rd-R_A} dx$ is the loss given default on deposits' return.

Equilibrium in the final good market requires that the production of the final good equals the sum of private consumption by households and entrepreneurs, investment, public spending,

and the resource costs that originate from the adjustment of prices. The combined resource constraints, inclusive of government budget, reads as follows:

$$Y_t = C_t + I_t + G_t + \frac{\vartheta}{2} (\pi_t - 1)^2 - \Omega_t - \Upsilon_t - \Delta_t \quad (29)$$

In the above equation, G_t is government consumption of the final good which evolves exogenously and is assumed to be financed by lump sum taxes. Notice that our model features two sources of output costs. First, the term $\Omega_t = \int_{-h}^{R_t - R_{A,t}} R_t^A (Q_{t-1} K_t)^{\frac{c}{2h}} dx_t$, represents the expected cost of run, while the term $\Upsilon_t = \mu R_t^K Q_{t-1} K_t \int_a^{\varpi_{t+1}} \omega_{t+1} f(\omega_{t+1}) d\omega$, is the monitoring costs paid by banks in case of firms' default. Both of them widen when the volatility of the corresponding idiosyncratic components widens.

4.5 Parameter values

Household preferences and production. The time unit is the quarter. The utility function of households is $U(C_t, N_t) = \frac{C_t^{1-\sigma} - 1}{1-\sigma} + \nu \log(1 - N_t)$, with $\sigma = 1$, as in most real business cycle literature. We set ν set equal to 3, chosen in such a way to generate a steady-state level of employment $N \approx 0.3$. We set the discount factor $\beta = 0.99$, so that the annual real interest rate is equal to 4%. We assume a Cobb-Douglas production function $F(\bullet) = K_t^\alpha (N_t)^{1-\alpha}$, with $\alpha = 0.3$. The quarterly aggregate capital depreciation rate δ is 0.025, the elasticity of substitution between varieties 6. The adjustment cost parameter is set so that the volatility of investment is larger than the volatility of output, consistently with empirical evidence: this implies an elasticity of asset prices to investment of 2.

In order to parameterize the degree of price stickiness ϑ , we observe that by log-linearizing equation 23 we can obtain an elasticity of inflation to real marginal cost (normalized by the steady-state level of output)¹² that takes the form $\frac{\varepsilon-1}{\vartheta}$. This allows a direct

¹²To produce a slope coefficient directly comparable to the empirical literature on the New Keynesian Phillips curve this elasticity needs to be normalized by the level of output when the price adjustment cost factor is not explicitly proportional to output, as assumed here.

comparison with empirical studies on the New-Keynesian Phillips curve such as Sbordone [36] using Calvo-Yun approach. In those studies, the slope coefficient of the log-linear Phillips curve can be expressed as $\frac{(1-\hat{\vartheta})(1-\beta\hat{\vartheta})}{\hat{\vartheta}}$, where $\hat{\vartheta}$ is the probability of not resetting the price in any given period in the Calvo-Yun model. For any given values of ε , which entails a choice of the steady state level of the markup, we can thus build a mapping between the frequency of price adjustment in the Calvo-Yun model $\frac{1}{1-\hat{\vartheta}}$ and the degree of price stickiness ϑ in the Rotemberg setup. The recent New Keynesian literature has usually considered a frequency of price adjustment of four quarters as realistic. Recently, Bils and Klenow [14] have argued that the observed frequency of price adjustment in the US is higher, in the order of two quarters. As a benchmark, we parameterize $\frac{1}{1-\hat{\vartheta}} = 4$, which implies $\hat{\vartheta} = 0.75$. Given $\varepsilon = 6$, the resulting stickiness parameter satisfies $\vartheta = \frac{Y\hat{\vartheta}(\varepsilon-1)}{(1-\hat{\vartheta})(1-\beta\hat{\vartheta})} \approx 30$, where Y is steady-state output.

Debt contract in the lending department. Parameters for the debt contract, μ and the volatility of corporate risk, σ_{ω}^2 , are calibrated following the financial accelerator literature and so as to generate a steady state solution for the external finance premium of 300 basis points. This delivers a value of the monitoring costs of 5% of asset value and a volatility of corporate risk, σ_{ω}^2 , of 0.3.

Banks. To calibrate h we have calculated the average dispersion of corporate returns from the data constructed by Bloom et al. [16] (we are grateful to Nick Bloom for giving us access to his data), which is 0.31, and multiplied this by the square root of 3, the ratio of the maximum deviation to the standard deviation of a uniform distribution. The result, 0.5, is our benchmark. To this we apply a shock as described in the next section.

One way to interpret λ is to see it as the ratio of two present values of the project, the first at the interest rate applied to firms' external finance, the second discounted at the bank internal finance rate (the money market rate). A benchmark estimate can be obtained by taking the historical ratio between the money market rate and the lending rate. In the US over the last 20 years, based on 30-year mortgage loans, this ratio has been around 3 percent.

This leads to a value of λ around 0.6. In the empirical analyses we have chosen a steady state value of 0.5, to which we apply a shock as described in the next section. Finally we parametrize the survival rate of banks, θ , at 0.97, a value compatible with an average horizon of 10 years. Notice that the parameter $(1 - \theta)$ is meant to capture only the exogenous exit rates, as the failure rate is linked to the distribution of the idiosyncratic shock to corporate returns. Entrepreneurs survival probability, ς , is set according to most parametrization in the financial accelerator literature, namely at a value of 0.975.

The parameter c can be set looking at statistics on recovery rates, available from Moody's. These rates tend to vary considerably, from below 50 percent up to 80 or 90 percent for some assets. We used a value of 70 percent, which implies $c = 0.3$.

Finally, the fraction ξ of bank versus market finance is parametrized at a benchmark value of 0.5. Sensitivity checks are done on the value of this parameter. A high value would indeed be consistent with practice in Anglo-Saxon financial markets, in which equity or corporate debt finance tends to prevail over bank finance, while a low value would be consistent with the practice in European financial markets, in which banks' finance tends to prevail.

Shocks. We introduce into the model two standard macro shocks and some risk shocks. The first, a productivity shock, is simulated in order to describe the transmission mechanism at work in our model. The monetary policy and the risk shock are simulated to analyze the risk taking channel. Total factor productivity is assumed to evolve as:

$$A_t = A_{t-1}^{\rho_\alpha} \exp(\varepsilon_t^\alpha) \quad (30)$$

where the steady-state value A is normalized to unity (which in turn implies $\omega_m = 1$) and where ε_t^α is an i.i.d. shock with standard deviation σ_α .

We introduce a monetary policy shock as an additive disturbance to the interest rate set through the monetary policy rule. The monetary policy shock is assumed to be moderately persistent (coefficient 0.2), as argued by Rudebusch [39]. Based on the evidence presented

in section 3, and consistently with other empirical results for US and Europe, the standard deviations of the shocks is set to 0.006.

The *risk shocks* are AR(1) stochastic component which affects both, the external finance premium and the market liquidity parameter, λ .

5 Model Results and Discussion

To recapitulate, our banking model features both a risk taking and a balance sheet channel. Following an increase in the interest rate, triggered e.g. by a monetary policy restriction or by a fall in aggregate productivity, the funding unit of the bank adjusts its risk profile by decreasing the share of short term liabilities and increasing the fraction of bank capital. This reduces funding risk and the probability of a run, as per equation 17. Over time the reduction in risk stimulates investment, therefore dampening the recessionary effects of the initial interest rate increase. On the other side, an increase in the interest rate, by reducing investment and asset prices on impact, depresses the value of firms' balance sheet, which in turn produces an increase in the external finance premium charged by the investment unit of the bank, as per equation 5. A direct consequences of the increase in the cost of loans is the increase in the firms' default probability. Hence, in response to an increase in the interest rate the balance sheet channel sharpens the recessionary effects of the shock by increasing the firms' default risk (the financial accelerator).

To gain some insight of the double role played by our intermediation sector we plot impulse responses to a monetary restriction and to a fall in productivity, comparing three models. The first model includes only the funding unit of the bank, as in AF, and hence features solely the risk taking channel. The second model is the classical financial accelerator, which includes only the lending unit of the bank. Hereafter we label this second model as BGG. The third model (which we label as AF_BGG) is the one described above, which includes both sides of the bank.

Figure 1 shows impulse response to a monetary restriction across the three models.

Notice that some variables, such as the deposit ratio and the bank riskiness, are specific to the AF and the AF_BGG models alone, while others, such as the external finance premium, are specific to the models with financial accelerator, namely BGG and AF_BGG. The figure shows that both the AF and the AF_BGG feature a risk taking channel, consistent with our data evidence: an increase in the interest rate induces the funding department of the bank to reduce the deposit ratio. This in turn reduces the probability of a run and bank riskiness. However, the decline in bank riskiness is lower in the mixed model (AF_BGG). The fall in the deposit ratio also triggers a fall in the bank lending premium BLP; this premium tends to be pro-cyclical under a monetary policy shock. Note that the risk taking channel is amplified in the AF_BGG relative to AF, as a consequence of the interaction of the two transmission channels.

AF_BGG produces milder output and investment responses than the other two models. This matches the stronger decline in bank leverage and risk, that tends *ceteris paribus* to have an expansionary effect. In the BGG model an increase in the interest rate triggers, as in the other two models, a fall in output, investment and asset prices. However in this case the fall in firms' net worth induces an increase in the EFP, which behaves countercyclically. The impact of the EFP on investment and output is quite strong relative to the other models.

Figure 2 shows responses of selected variables to a productivity increase. Again, BGG is the model that features the strongest effect on output. This matches the fact that the EFP and the firms' default probability decline more than in the AF_BGG model. Again, the risk taking channel acts to dampen the expansionary effect of the initial shock, via an increase in bank riskiness. Unlike in the previous case, BLP is countercyclical now: the relation between this premium and the business cycle cannot be signed a-priori but depends on the nature of the shock. Under a productivity shock, the bank increases its risk exposure in response to the improved investment opportunities; the overall net effect is expansionary, as expected, but the risk taking channel has a moderating influence. Note also that bank risk increases but corporate risk decreases. The reason is intuitive: on the corporate side, an increase in

productivity produces a fall in interest rates, which in subsequent periods boosts asset prices and the value of corporate balance sheet; the external finance premium and the probability of corporate default declines. On the bank side, the decline in interest rates induces banks accept a higher balance sheet risk.

We now examine how banks react to a market risk shock. We envisage this shock as consisting in a temporary, but persistent, decline in asset prices accompanied by decline in market liquidity, making harder for corporates to liquidate assets or use them as collateral to obtain external finance. We model such shock as a simultaneous persistent disturbance in the early liquidation value without banks (parameter λ , moving down), in the EFP (parameter ρ , moving up) alongside with a decline in Tobin's q ¹³. Figure 3 shows that the systemic risk shock is contractionary in all models, consistently with our data evidence, but timing and strength of the effects differ across our models. Bank leverage and risk go up in the AF_BGG, relative to AF, but this contractionary effect stemming from the risk taking channel is more than compensated on impact by the increase in bank lending premium, hence output contracts more on impact in AF than in the "mixed model" AF_BGG. Interestingly, in the AF model under this "market risk" shock the riskiness of banks declines (marginally) on impact, due to the fact that banks, having acquired more relationship lending power, are able to raise lending rates more (hence the increase on BLP). On the other side, in the BGG model the riskiness of firms increase. The "mixed" AF_BGG model is somewhere in between in this respect. In this model, BLP declines and moves pro-cyclically, as in the monetary policy shock.

6 Conclusions

After the financial crisis, a reflection is underway on what the lessons can be learned for the transmission of monetary policy to and through the financial sector, taking into account financial risks and their determinants. This has wide-ranging implications for the conduct

¹³For simplicity, we do not calibrate the size of the shock in any specific way, but assume a 1 percent change for all. The qualitative results are not affected.

of other policies as well, notably in the financial regulatory and supervisory fields.

This paper contributes to this investigation by presenting data and model evidence on the effects of monetary policy on risk-taking behavior in the corporate and banking sectors. To do so, it proposes a new macro model with banks and a financial sectors and compares it with existing more traditional models.

The preliminary conclusions may be summarized under two headings. First, there is evidence that the stance of monetary policy affects, with lags, the propensity of financial markets and banks to assume risk. On this, our results are supportive of other evidence appeared recently in the literature. Second, it is possible to specify macroeconomic models embodying optimizing agents with limited information and including explicitly banking and financial sectors, that rationalise this behavior. Our own model combines banks with endogenous balance sheet and funding risk with a financial accelerator on the bank lending side. The matching between this model and the data seems promising and encourages further research along this line.

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7 Appendix 1. Expected Loss on Risky Deposits

We want to calculate is the expected return on deposits, taking into account the fact that given the possibility of run, the expected return is below the riskless return.

Consider the return on deposits in the three possible events: run for sure, run only without bank, and no run for sure.

In the **first case** (run for sure), the payoff to the depositor is $\frac{(1+\lambda)(1-c)(R_A+x)}{2}$. This holds in the interval of x comprised between $[-h; (Rd - R_A)]$. The expected value of this component of return is $\frac{1}{2h} \int_{-h}^{Rd-R_A} \frac{(1+\lambda)(1-c)(R_A+x)}{2} dx$. The expected return on deposits **conditional** on a run is $\frac{(1+\lambda)(1-c)}{2} [R_A + \frac{(Rd-R_A)-h}{2}]$. This can be obtained alternatively in two ways; either by dividing $\frac{1}{2h} \int_{-h}^{Rd-R_A} \frac{(1+\lambda)(1-c)(R_A+x)}{2} dx$ by the probability of run $\frac{1}{2h} \int_{-h}^{Rd-R_A} dx$ and solving, or more intuitively by replacing x in $\frac{(1+\lambda)(1-c)(R_A+x)}{2}$ with its expected value in case of a run, $\frac{(Rd-R_A)-h}{2}$. Note that the latter expression is simply the midpoint between $-h$ and $(Rd - R_A)$, two negative numbers in our calibration. Intuitively, the mean is equal to the midpoint because the distribution is uniform.

In the **second case** (run only without bank) as well as in the **third case** (never run) the conditional return to the depositor is the same and equal to the riskless return Rd , independent of x . The total probability of this event is $\frac{1}{2h} \int_{Rd-R_A}^h dx$.

The expected return on deposits per unit of investment (ρ_I), is given by sum of the conditional returns in the two events multiplied by their probability:

$$\rho_I = \rho_I |_{run} z + Rd(1 - z)$$

$$\text{where } z = \frac{1}{2h} \int_{-h}^{Rd-R_A} dx \text{ and } \rho_I |_{run} = \frac{(1+\lambda)(1-c)}{2} [R_A + \frac{(Rd-R_A)-h}{2}].$$

This can also be written as

$$\rho_I = Rd - z(Rd - \rho_I |_{run}) = Rd \left[1 - z \left(\frac{Rd - \rho_I |_{run}}{Rd} \right) \right]$$

The expected loss on deposits is $Rd - \rho_I |_{run} = z \left(\frac{Rd - \rho_I |_{run}}{Rd} \right)$. Note that this is equal to the loss conditional on default multiplied by z , the probability of default.

8 Appendix 2: The Bank Lending Side (not for publication)

The credit side is modelled as a standard financial accelerator (Bernanke et al. [11], Faia and Monacelli [25]). The investment projects financed by the bank are characterized by an expected return equal to $R_{t+1}^K Q_t K_{t+1}$, where R_{t+1}^K , Q_t and K_{t+1} are respectively the nominal return on capital, the price of capital and real capital (individual subscripts are omitted for brevity, also since ex-post the linearity characterizing the finance premia and the loan schedule allow us to aggregate according to representative firms and banks). Project outcomes are subject to idiosyncratic uncertainty, taking the form of a multiplicative random shock applied to productivity. The shock ω is assumed to have a uniform density function $f(\omega)$, with support $[a, b]$; hence $\omega \in (a, b)$; $f(\omega) = \frac{1}{b-a}$; $E(\omega) = \frac{a+b}{2}$. Therefore, the monetary return of an investment project financed at t is given by $\omega_{t+1} R_{t+1}^K Q_t K_{t+1}$.

The contract between the firm and the lending department stipulates ex-ante a fixed gross return for the bank R_{t+1}^{BF} and a financing amount $EF_{t+1} = Q_t K_{t+1} - NW_{t+1}$, where NW_{t+1} is the entrepreneur's net worth. EF_{t+1} includes a fixed proportion $1 - \xi$ of own bank funds, L_{t+1} , while the rest is raised by issuing corporate bonds. Ex-post there are two cases. If the firm doesn't default, it pays back the debt, inclusive of the contractual return R_{t+1}^{BF} , and the entrepreneur retains any surplus. If not, the firm goes bankrupt and the lending department liquidates the project. In this case, the lender has to bear a monitoring cost equal to a fraction μ of the project value. Formally, the contract defines a default threshold return $\bar{\omega}$ such that bankruptcy of the firm occurs only if $\omega < \bar{\omega}$, where $\bar{\omega}$ is defined by

$$\varpi_{t+1} \equiv \frac{R_{t+1}^{BF} EF_{t+1}}{\mathcal{Y}_{t+1}^k K_{t+1}} \quad (31)$$

where \mathcal{Y}_{t+1}^k is the unitary monetary return from holding a unit of capital and is equal to $\mathcal{Y}_{t+1}^k = R_{t+1}^K Q_t$. This variable, alongside with R_{t+1}^K and Q_t , will be specified below when solving the optimization problem of capital producers.

For each nominal unit lent, the expected return for the lender is:

$$\Gamma(\varpi_{t+1}) \equiv \left(\int_a^{\varpi_{t+1}} \omega_{t+1} f(\omega_{t+1}) d\omega + \int_{\varpi_{t+1}}^b \varpi_{t+1}^j f(\omega_{t+1}) d\omega \right)$$

and the expected return to the firm is the complement, $1 - \Gamma(\varpi_{t+1})$. The cost of monitoring is

$$M(\varpi_{t+1}) \equiv \int_a^{\varpi_{t+1}} \omega_{t+1} f(\omega_{t+1}) d\omega$$

and the net unit return accruing to the lender is $\Gamma(\varpi_{t+1}) - \mu M(\varpi_{t+1})$.

The firm's investment is financed by a mix of internal and external funds. A fraction ξ is financed by external funds from the bank, which gets an average return R_t^A , while the remaining part is financed through corporate debt, which is held by households, who for this asset receive the same risk free rate than for deposits, namely R_t . The participation constraint for the lender thus takes the form:

$$[(1 - \xi)R_t^A + \xi R_t] (Q_t K_{t+1} - NW_{t+1}) \leq \mathcal{Y}_{t+1}^k K_{t+1} (\Gamma(\varpi_{t+1}) - \mu M(\varpi_{t+1})) \quad (32)$$

The contract between the lender and the firm specifies a pair $\{\varpi_{t+1}, EF_{t+1}\}$ which solves the maximum problem:

$$Max (1 - \Gamma(\varpi_{t+1})) \mathcal{Y}_{t+1}^k K_{t+1} \quad (33)$$

subject to 32. The first order conditions read as follows:

$$\Gamma'(\varpi_{t+1}) = \chi_t (\Gamma'(\varpi_{t+1}) - \mu M'(\varpi_{t+1})) \quad (34)$$

$$\frac{R_{t+1}^K}{[(1-\xi)R_t^A + \xi R_t]} \left((1 - \Gamma(\varpi_{t+1}^j)) + \chi_t(\Gamma(\varpi_{t+1}^j) - \mu M(\varpi_{t+1}^j)) \right) = \chi_t \quad (35)$$

where χ_t is the Lagrange multiplier. For $\chi_t > 0$ (32) must hold with equality.

Solution of the above first order conditions yields the following relation between the expected return on capital and the safe return paid on deposits:

$$E_t \{ R_{t+1}^k \} = \rho(\varpi_{t+1}) [(1-\xi)R_t^A + \xi R_t]$$

where

$$\rho(\varpi_{t+1}) = \left[\frac{(1 - \Gamma(\varpi_{t+1}))(\Gamma'(\varpi_{t+1}) - \mu M'(\varpi_{t+1}))}{\Gamma'(\varpi_{t+1})} + (\Gamma(\varpi_{t+1}) - \mu M(\varpi_{t+1})) \right]^{-1} \quad (36)$$

with $\rho'(\varpi) > 0$.

Let's define $\rho(\varpi_{t+1}) \equiv E_t \left\{ \frac{R_{t+1}^k}{[(1-\xi)R_t^A + \xi R_t]} \right\}$ as the *premium on external finance*. By combining (32) with (36) one can write a relationship between capital expenditure $Q_t K_{t+1}$ and net worth NW_{t+1} whose proportionality factor depends endogenously on ψ_t :

$$Q_t K_{t+1} = \left(\frac{1}{1 - \rho(\varpi_{t+1})(\Gamma(\varpi_{t+1}) - \mu M(\varpi_{t+1}))} \right) NW_{t+1} \quad (37)$$

One can view (37) as a demand equation, in which the demand of capital depends inversely on the price and positively on the aggregate financial conditions. On the other hand, one can write the finance premium ψ_t as:

$$\rho(\varpi_{t+1}) = \frac{R_{t+1}^K}{[(1-\xi)R_t^A + \xi R_t]} = h(\varpi_{t+1}) \left(1 - \frac{NW_{t+1}}{Q_t K_{t+1}} \right) \quad (38)$$

where $h(\varpi_{t+1}) \equiv [\Gamma(\varpi_{t+1}) - \mu M(\varpi_{t+1})]^{-1}$. One can easily show that $h'(\bullet) > 0$. This expression suggests that the external finance premium is an equilibrium inverse function of the aggregate financial conditions in the economy, expressed by the (inverse) leverage ratio $\frac{NW_{t+1}}{Q_t K_{t+1}}$.

Entrepreneurs are finitely lived: this assumption is needed in order to avoid that they accumulate enough wealth, thereby making the intermediary unnecessary. The survival

probability, ς , is the fraction of entrepreneurs who remain in business in each period. Hence, the aggregate net worth for the firm, in expected terms, accumulates over time according to

$$NW_{t+1} = \varsigma(1 - \Gamma(\varpi_{t+1}))\mathcal{Y}_t^k K_t \quad (39)$$

In other words, next period net worth is given by the expected returns accruing to the entrepreneurs who do not exit the market. Rearranging and using 32 one can write this as

$$NW_{t+1} = \varsigma R_t^K Q_{t-1} K_t - \varsigma \{[(1 - \xi)R_{A,t} + \xi R_t] + m_t\} (Q_{t-1} K_t - NW_t) \quad (40)$$

where $m_t = \frac{M(\varpi_t)R_t^K Q_{t-1} K_t}{Q_{t-1} K_t - NW_t}$ is the expected monitoring cost per unit of loan.

Table 1: Granger Causality Tests**Panel A. United States**

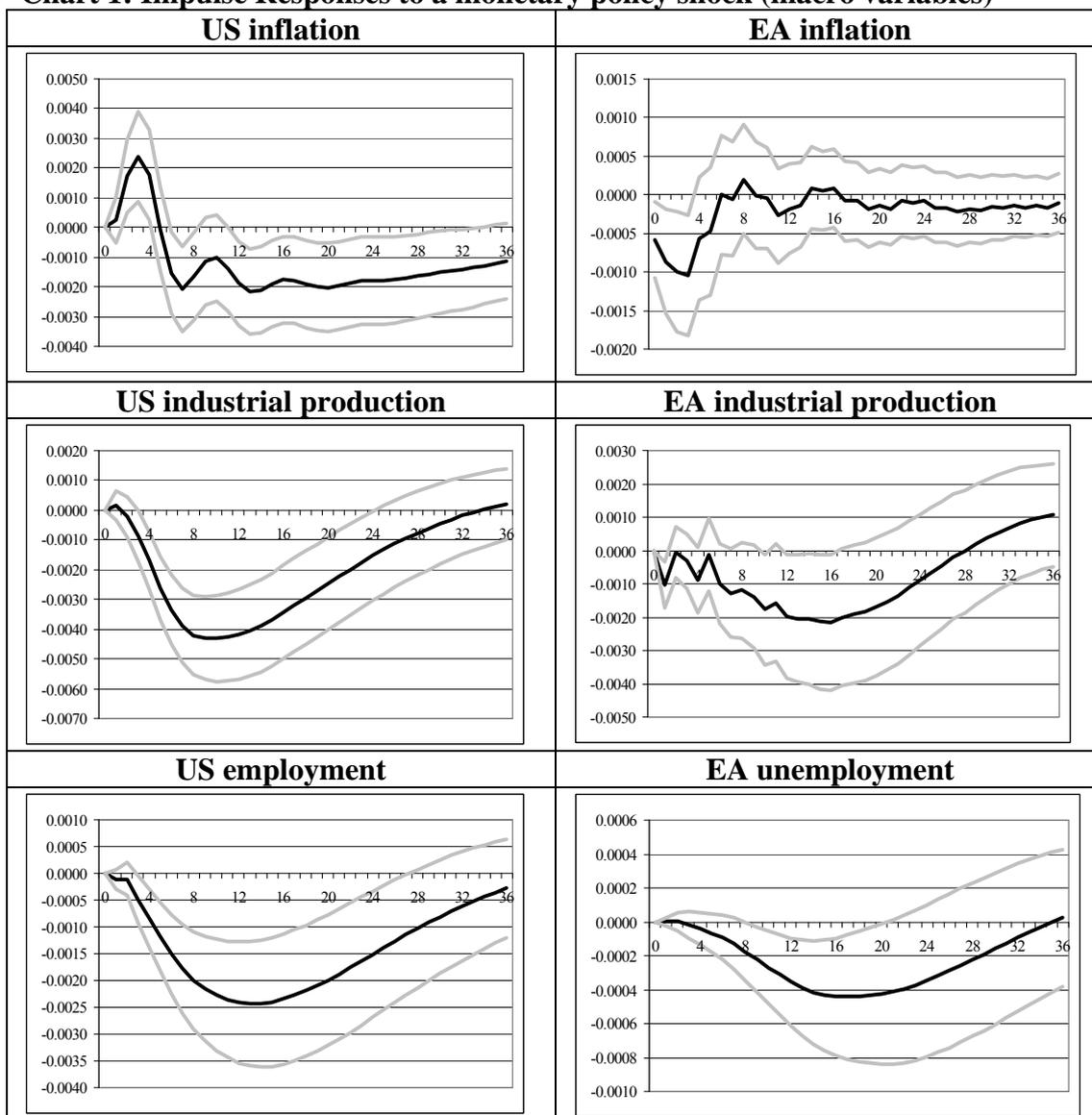
Equation	Excluded	Lags	p-Value
monetary policy	funding risk I	25	0.321
funding risk I	monetary policy	25	0.002 ***
monetary policy	funding risk II	17	0.591
funding risk II	monetary policy	17	0.058 *
monetary policy	asset risk I	14	0.672
asset risk I	monetary policy	14	0.133
monetary policy	asset risk II	25	0.900
asset risk II	monetary policy	25	0.005 ***
monetary policy	asset risk III	14	0.540
asset risk III	monetary policy	14	0.030 **
monetary policy	asset risk IV	25	0.855
asset risk IV	monetary policy	25	0.009 ***

Panel B. Euro Area

Equation	Excluded	Lags	p-Value
monetary policy	funding risk I	13	0.001 ***
funding risk I	monetary policy	13	0.954
monetary policy	funding risk II	5	0.002 ***
funding risk II	monetary policy	5	0.016 **
monetary policy	asset risk I	18	0.000 ***
asset risk I	monetary policy	18	0.233
monetary policy	asset risk II	19	0.000 ***
asset risk II	monetary policy	19	0.000 ***
monetary policy	asset risk III	3	0.090 *
asset risk III	monetary policy	3	0.042 **
monetary policy	asset risk IV	13	0.316
asset risk IV	monetary policy	13	0.113

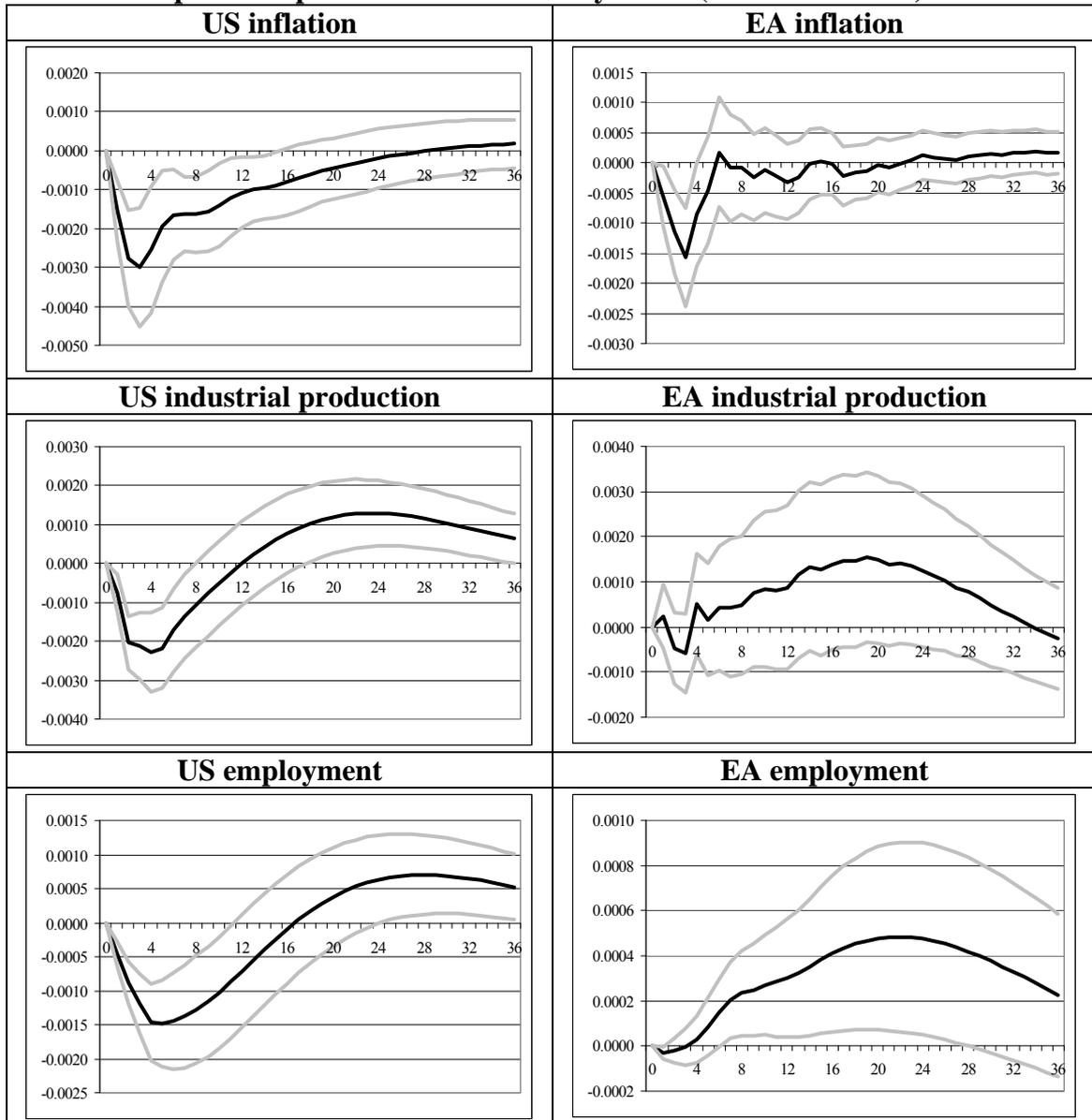
Notes: The table reports the results of Granger causality tests of bivariate VAR models, where the endogenous variables are monetary policy (de-trended effective federal fund rate) and different indicators capturing funding and asset risk of banks (see table A1 for the description of the variables). Column “Equation” specifies the dependent variable; column “Excluded” reports the variable excluded from the equation; column “Lags” specifies the number of lags used in the estimation of the VAR model, lags are selected by looking at Akaike information criterion. Column “p-value” specifies the p-value of the granger causality test, rejection at 1% (5%) confidence level is marked with *** (**).

Chart 1: Impulse Responses to a monetary policy shock (macro variables)



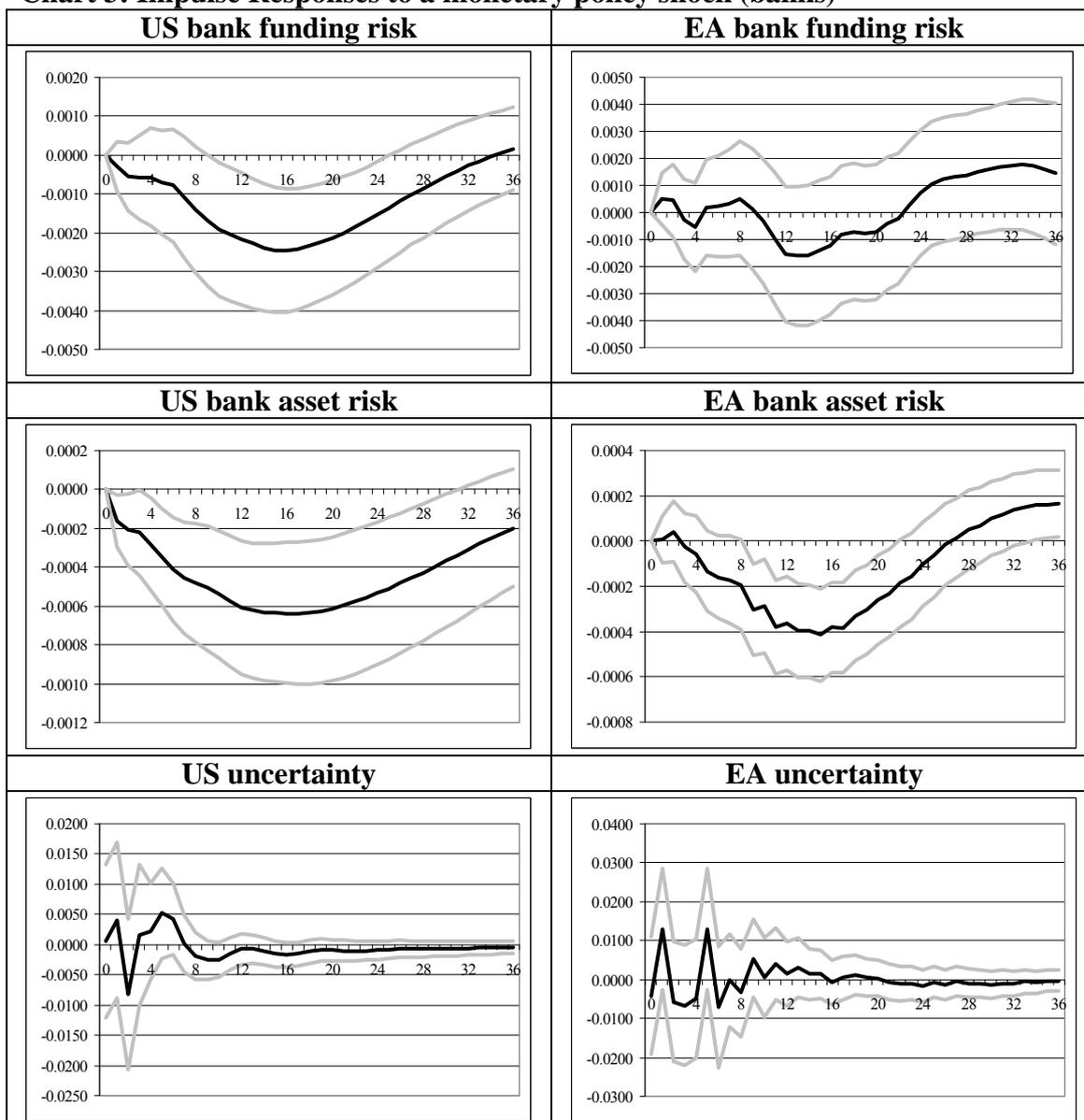
Notes: for the calculation of impulse responses we use the same estimation order of the variables as in Bloom et al. (2010), with the difference that we insert the bank asset risk and funding risk variables between the macro and the financial block. Therefore, the variables in the estimation order are industrial production, employment, inflation, asset risk, funding risk, monetary policy rate, the stock market volatility indicator and the stock market index. The ordering used here is based on the assumption that shocks instantaneously influence the stock market (levels and volatility), then the interest rate. Subsequently bank balance sheet variables adjust, followed by macro adjustments (first the price index and then quantities). As it is not clear which bank risk proxy variable should be placed first, we estimate different VAR models inverting the order of these two variables. The results are not affected. For the US, the model is estimated with monthly data from January 1974 to June 2008. For the euro area the sample covers the period March 1991 to December 2008.

Chart 2: Impulse Responses to an uncertainty shock (macro variables)

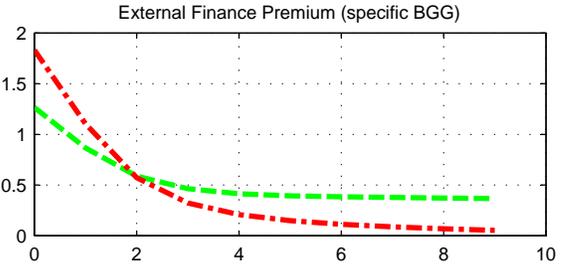
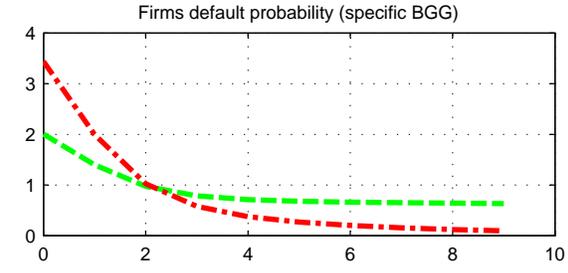
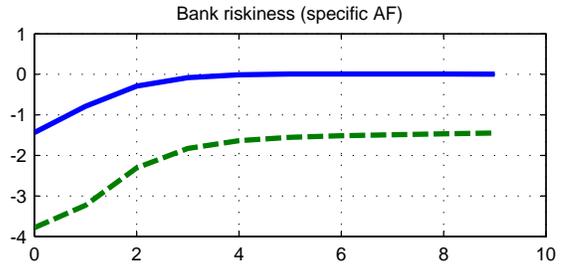
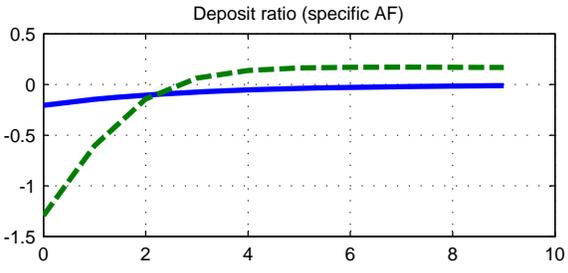
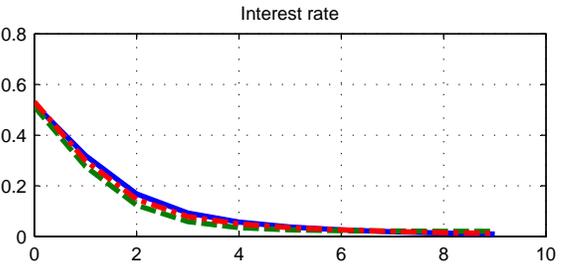
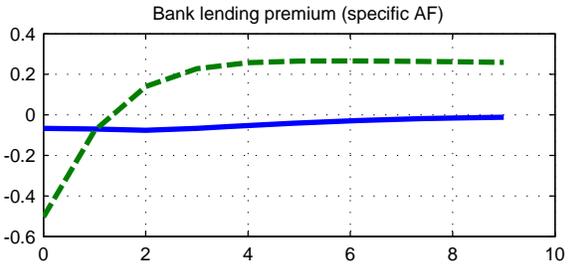
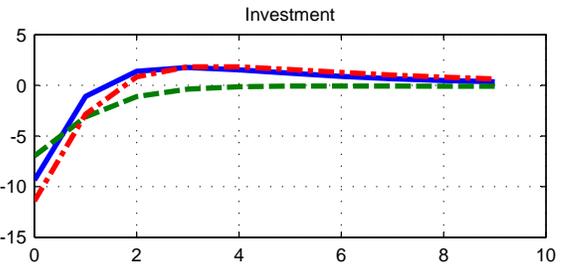
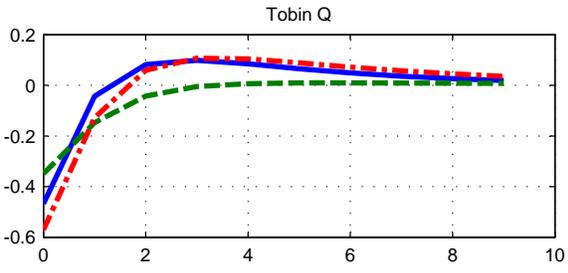
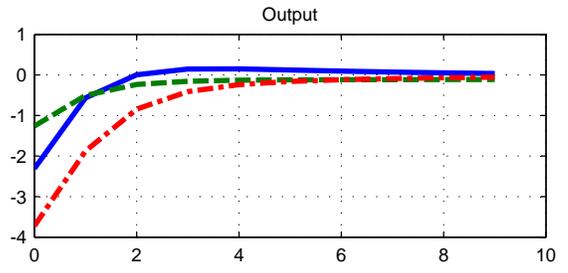
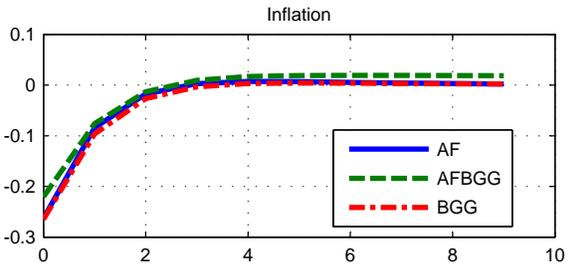


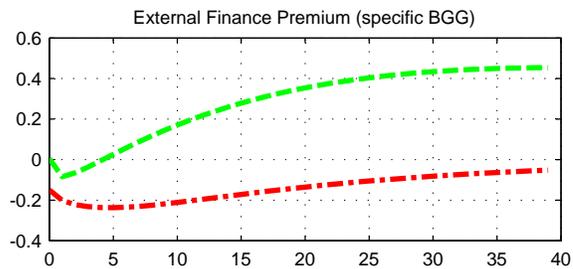
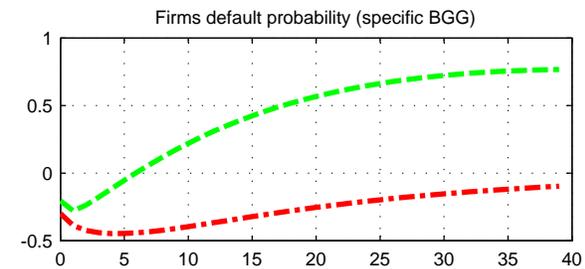
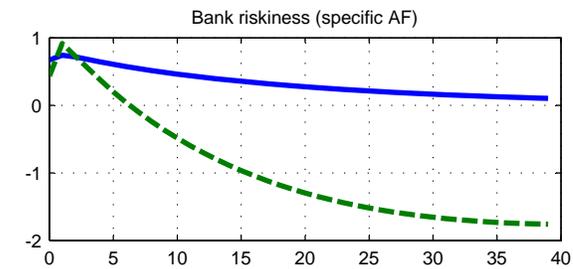
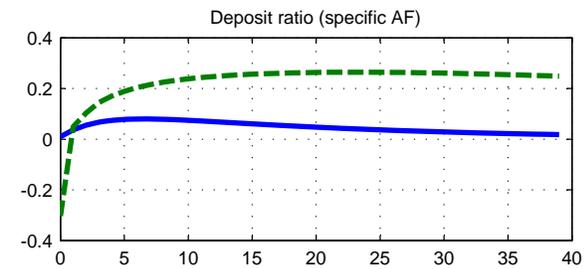
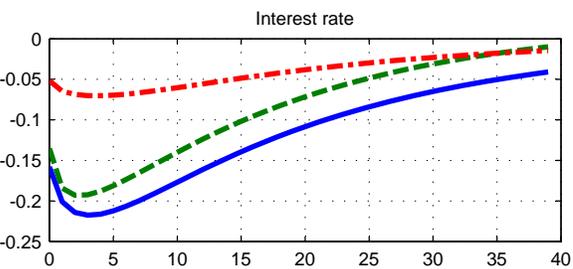
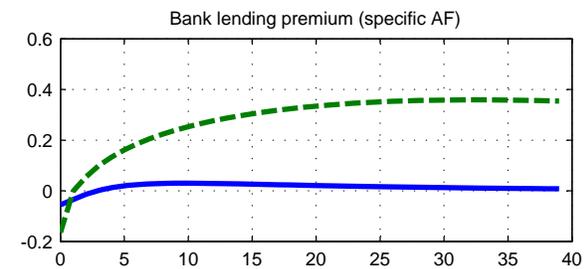
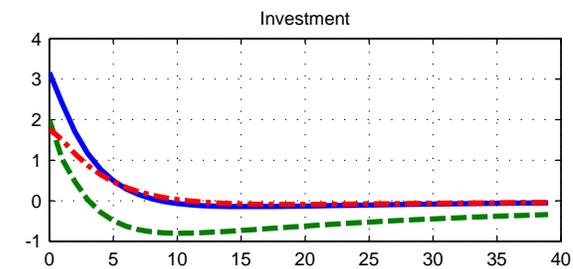
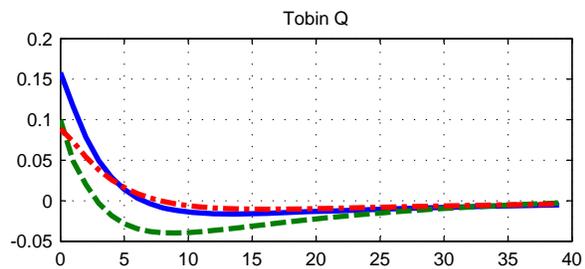
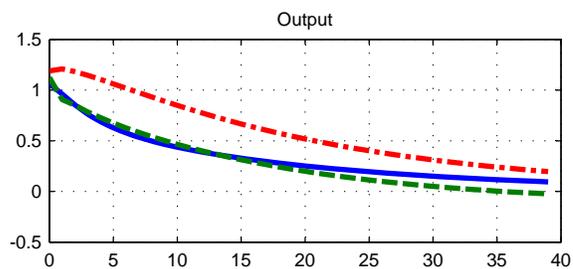
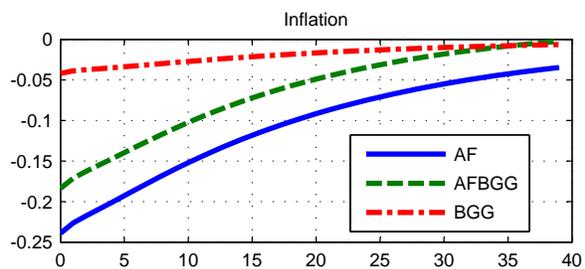
Notes: see notes to chart 1.

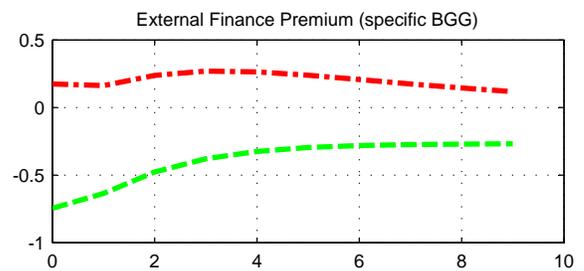
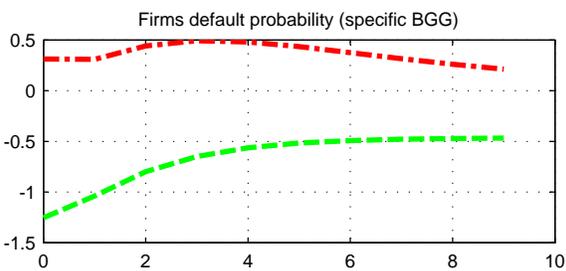
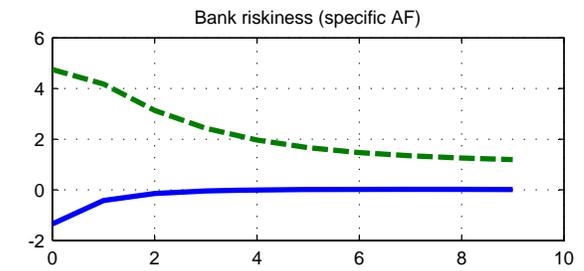
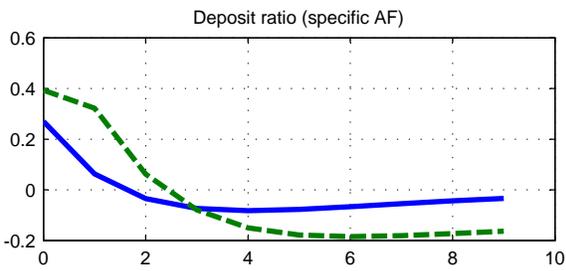
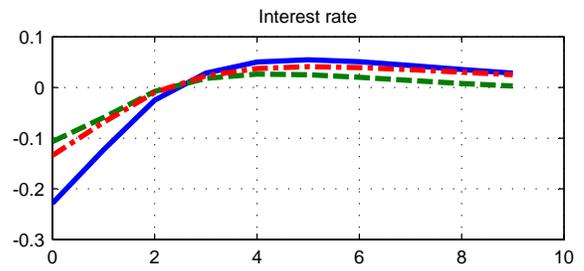
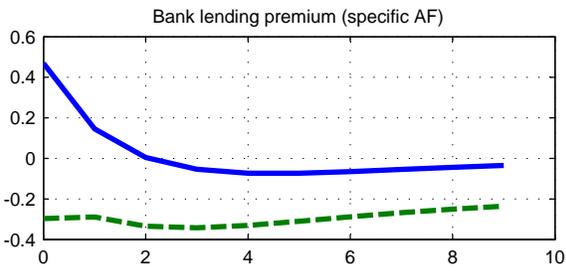
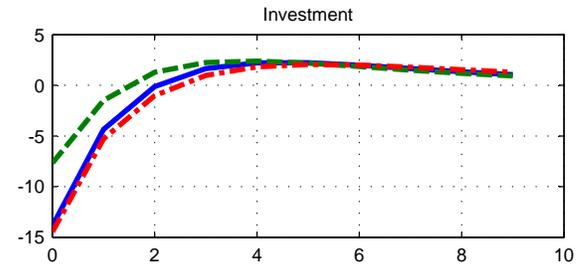
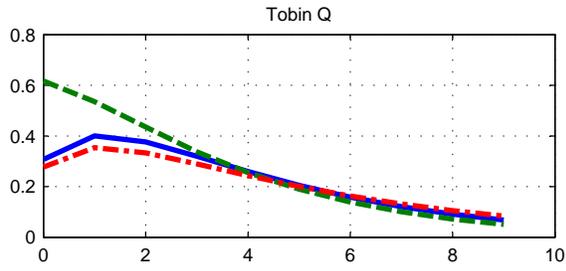
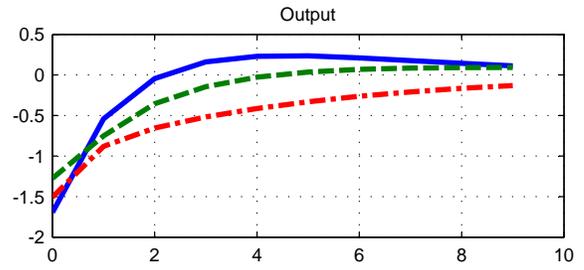
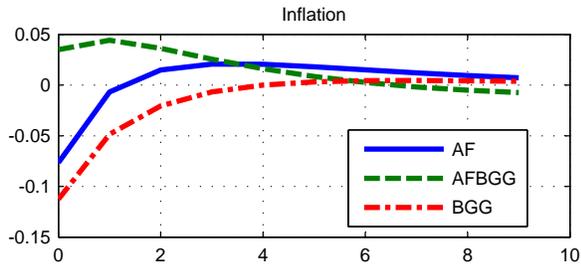
Chart 3: Impulse Responses to a monetary policy shock (banks)



Notes: The impulse response of funding risk to a monetary policy shock for the euro area was estimated over the period January 2000 – December 2008, as it was only possible to compute the funding risk index after January 2000. The impact of monetary policy on uncertainty is estimated using the volatility index calculated by Bloom (2010) for the US and an equivalent volatility index for the euro area. See also notes to chart 1.







APPENDIX A: Variables Description - United States

Variable name	Description	Baseline Model
Stock market	De-trended logarithm of the S&P500 index. Source: Authors' calculation and Datastream	Y
Monetary policy rate	De-trended effective Federal Fund rate. Source: Authors' calculation and FED.	Y
Inflation	Annualised rate of change of the CPI over the last 3 months. Source: Authors' calculation and FED.	Y
Industrial production	De-trended logarithm of the industrial production index for manufacturing industries. Source: Authors' calculation and BEA.	Y
Employment	De-trended logarithm of total employment in manufacturing. Source: Authors' calculation and BEA.	Y
Uncertainty shock I (RISK1)	Binary variable equal to one when the implied volatility of the stock market index is above the mean plus 1.65 times the standard deviation, zero otherwise. Source: Bloom (2009)	Y
Asset risk I (RISK2)	De-trended ratio of consumer credit and mortgages over total assets. Source: Authors' calculation and FED.	Y
Funding risk I (RISK3)	12 month difference of the ratio total assets to total deposits. Source: Authors' calculation and FED.	Y
Uncertainty shock II	Implied volatility of the stock market index. Source: Bloom (2009)	N
Asset risk II	12 month difference of the ratio consumer credit and mortgages to total assets. Source: Authors' calculation and FED.	N
Asset risk III	De trended ratio consumer credit and mortgages to total assets minus treasury bonds. Source: Authors' calculation and FED	N
Asset risk IV	12 month difference of the ratio consumer credit and mortgages to total assets minus treasury bonds. Source: Authors' calculation and FED	N
Funding risk II	De trended ratio total assets to total deposits. Source: Authors' calculation and FED.	N

Notes: The column "Baseline Model" indicates the variables that enter into our baseline model. De-trending has been done with the Hodrick-Prescott filter ($\lambda = 129600$)

APPENDIX A (cont.): Variables Description - euro area

Variable name	Description	Baseline Model
Stock market	De-trended logarithm of the Eurostoxx index. Source: Authors' calculation and Datastream	Y
Monetary policy rate	De-trended EONIA rate (de-trended German overnight rate before 1999). Source: Authors' calculation and ECB.	Y
Inflation	Annualised rate of change of the HCPI over the last 3 months. Source: Authors' calculation and ECB.	Y
Industrial production	De-trended logarithm of the industrial production index for manufacturing. Source: Source: Authors' calculation and OECD.	Y
Employment	De-trended logarithm of total employment ¹ . Source: Authors' calculation and Eurostat.	Y
Uncertainty shock I (RISK1)	This is the same variable used for the US, see the description of "Uncertainty Shock I" for the US.	Y
Asset risk I (RISK2)	De-trended ratio of consumer credit and mortgages over total assets. The series starts in 1999. Source: Authors' calculation and ECB.	Y
Funding risk I (RISK3)	12 month difference of the ratio total assets to total deposits. The series starts in 1997. Source: Authors' calculation and ECB	Y
Uncertainty shock II	Implied volatility of the stock market index. Source: Datastream	N
Asset risk II	12 month difference of the ratio of consumer credit and mortgages over total assets. Source: Authors' calculation and ECB	N
Asset risk III	De-trended ratio of consumer credit and mortgages over total assets. The series start in 1991. Calculated by aggregating data for 6 euro area countries. ² Source: ECB and authors' calculations.	N
Asset risk IV	12 month difference of the ratio consumer credit and mortgages over total assets. The series start in 1991. Calculated by aggregating data for 6 euro area countries (see the description of "Asset risk III"). Source: ECB and authors' calculations	N
Funding risk II	De-trended ratio total assets to total deposits. Source: Authors' calculation and ECB	N

¹ Quarterly employment data have been converted to monthly frequency by linear interpolation.

² Available countries are France, Finland, Germany, Netherlands, Spain and Portugal. The series is transformed from quarterly to monthly frequency by linear interpolation.