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MONETARY POLICY EFFECTS ON BANK RISK TAKING

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Monetary policy effects on bank risk taking

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Abstract

The contribution of this paper is twofold. First, we provide empirical evidence on the existence of a risk-taking channel in the US economy. By identifying a Bayesian VAR through sign restrictions, we find that an expansionary monetary policy shock causes a persistent increase in proxies for bank risk-taking behaviour. We then develop a New Keynesian model with a risk-taking channel, where low levels of the risk free rates induce banks to extend credit to riskier borrowers. Conditional on calibration values, the simulated responses of key banking sector variables is compatible with the transmission mechanism observed in the data.

J.E.L. Classification: E12 E44 E58 C11

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1 Introduction

The recent financial crisis has marked the importance of keeping track of the different types of risk to which the financial sector, and ultimately the real economy, are exposed. An important aspect is the role that low interest rates, and therefore monetary policy, might play in influencing the risk-taking behaviour of financial intermediaries. This transmission mechanism, known as the risk-taking channel of monetary policy¹, could have contributed to the excessive risk exposure of the financial sector in the lead-up to the 2008 crisis. More recently, unconventional monetary policies enacted worldwide have caused a protracted decline in interest rates, raising concerns on whether financial market participants might be induced to reallocate portfolios towards riskier and more profitable investments, exposing one more time the economy to the risk of a financial crisis².

Despite representing an important policy question, there are still very few theoretical models that account for the presence of a bank risk-taking channel. Angeloni et al. [2013] have proposed a general equilibrium model where monetary policy influences the funding choice of banks, and therefore their level of funding risk, which arises from the possibility of bank runs. They do not model however how lax monetary policy might induce financial intermediaries to extend credit to riskier borrowers, another relevant trait of the recent financial crisis. The impact of monetary policy on bank asset risk is instead modelled in a micro framework by Dell’Ariccia et al. [2014]. Their modelling framework is however not suitable to answer policy questions such as evaluating the relevance of the risk-taking channel, or assessing how monetary policy should behave given this mechanism. The goal of this paper is to extend the micro model of Dell’Ariccia et al. [2014], embedding it in a general-equilibrium framework. The resulting model is a tool that will be used in future work to study how monetary policy should be conducted in a risk-taking channel environment. To our knowledge there is no other work that shares the same goal and, by modelling the influence of monetary policy on bank asset risk, we complement the work Angeloni et al. [2013].

As a second contribution, we assess to what extent the propagation mechanism of monetary policy described in our model matches the responses observed in the data. The model validation is achieved by comparing the simulated impulse-response functions from the model with those from a vector autoregression on US data, identified using robust sign restrictions, i.e. independent from the theoretical model being assessed. We find that an expansionary monetary policy shock persistently increases bank asset risk, a conclusion which is robust to alternative identification and estimation procedures. Moreover, an unexpected fall in the risk-free interest rate causes a decline in both the return on loans and in the cost of deposits, thereby simultaneously affecting banks’ revenues and funding costs, mirroring the model’s transmission mechanism.

This paper is organised as follows. In the next Section we review the empirical evidence on the risk-taking channel of monetary policy. The empirical evidence on the risk-taking channel is presented in Section 3, while the theoretical model and its implications are discussed in Section 4. Section 6 concludes.

¹The term was first coined by Borio and Zhu [2008].

²See for instance: (2014, 22 March). *Staying Unconventional*, *The Economist*.

2 A brief review of the empirical evidence on the risk-taking channel

As far as the empirical analyses are concerned, the investigation of the causal link between loose monetary policy and risk taking has primarily relied on bank-specific data. Jimenez et al. [2014] use micro data of the Spanish Credit Register from 1984 to 2006 and find that lower interest rates have a double-sided effect on the default probability of bank loans. This probability falls in the short-term, as the cost of interest payments decreases, but rises in the long-run, as a result of banks lending money to riskier borrowers in exchange for a higher yield. This conclusion is shared by Altunbas et al. [2010], who instead study the determinants of the expected default probabilities of a panel of listed banks from 16 OECD countries. Results highlight how an interest rate which is below that implied by the Taylor rule can significantly increase the expected default probability of banks.

A multivariate analysis of the effects of monetary policy on bank risk is provided by Angeloni et al. [2013], who focus on bank funding risk as well as on a proxy for overall banking risk, measured as the realised volatility in bank stock prices. Using a recursive identification scheme on monthly data between 1985 and 2008, they find that a monetary policy expansion decreases bank risk on impact, but increases it after a lag. No significant reaction to monetary policy is instead found when a measure of bank asset risk is used. Their evidence suggests therefore that lower interest rates increase the risk related to the bank funding structure, rather than to their asset structure. A complementary conclusion is reached by Buch et al. [2013] who estimate a FAVAR on a large dataset of banking-sector variables and estimate a monetary policy shock recursively, with the federal funds rate ordered last and after the unobserved banking factors. The authors find that an expansionary monetary policy shock induces small domestic banks to increase the fraction of risky loans in their portfolios, while charging a lower risk premium.

3 The effects of monetary policy shocks on the banking sector

In this Section we provide additional empirical evidence on the existence and functioning of the bank risk-taking channel in the US. Our starting point is a Bayesian VAR that includes the effective federal funds rate, taken as the monetary policy instrument, a measure of bank risk taking, as well as inflation and output. The latter is measured by real GDP, while inflation is defined as the annualised log change in the GDP deflator, in percentage terms. As discussed later, the length of the estimation sample is limited by the availability of data for bank risk-taking, and we employ a Bayesian estimation procedure to enhance the information set via prior specification. Identification of the monetary policy shock is achieved through sign restrictions that do not involve the measure of bank risk, and are in this sense agnostic. We find that an unexpected decrease in the risk-free interest rate causes a persistent increase in bank risk-taking, a result robust to alternative estimation and identification procedures. To better gauge the functioning of the risk-taking channel, we augment the core model with one additional banking-sector variable: in turn, real loans, and interest rates such as the return on loans, on deposits and on equity. These variables are chosen in order to capture the developments of bank revenues and funding costs after a monetary policy expansion and to understand why bank risk actually increase. This latter step is a distinctive feature of

our empirical analysis, together with the estimation and identification procedures used. Finally, the results of this Section serve as a benchmark to assess the implications of the general equilibrium model proposed in this paper³.

3.1 Measuring bank risk-taking behaviour

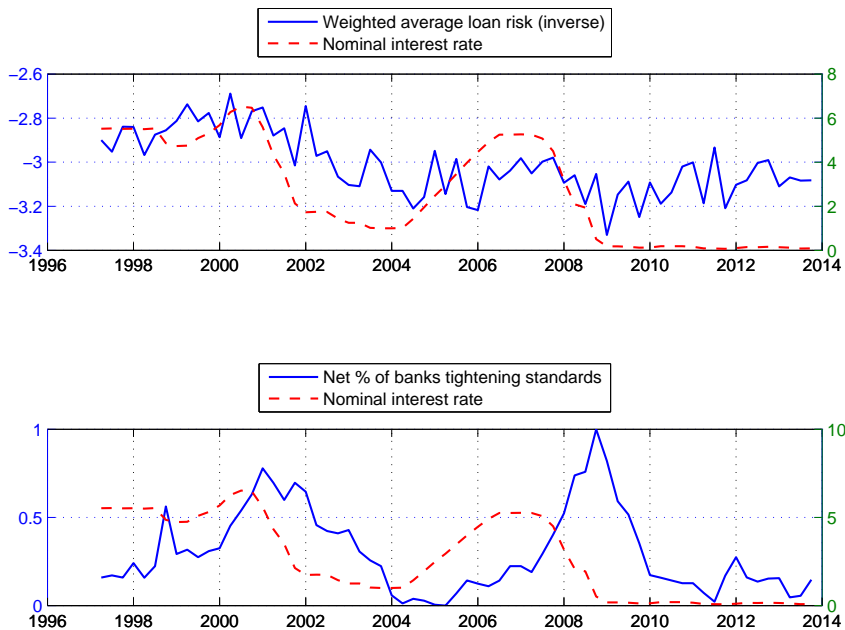
Bank asset risk can be distinguished in ex-ante and ex-post asset risk. The former is the risk perceived by the bank when making a loan or buying an asset. Banks can influence this class of risk directly, when making their investment decisions. At the same time, the risk of the total bank balance sheet is also affected by unforeseen changes in the riskiness of assets, that happen after origination and are largely outside the banks' influence (ex-post risk). Given that we are interested in active bank risk taking, we focus on measures of ex-ante asset risk, proxied with two variables available from surveys on US business lending. The first variable is the net percentage of banks reporting to have tightened lending standards over the previous quarter. It is derived from the Senior Loan Office Survey, a qualitative questionnaire in which loan officers from 60 large US domestic banks, accounting for approximately 60% of business lending, report whether they have tightened or eased lending standards over the previous quarter. The survey was conducted between 1968 and 1984, and started again after an interruption in 1990-Q2. Though this net percentage captures the change in lending standards, as opposed to their level, it could nevertheless be considered as a rough indicator for the level of bank risk-taking behaviour. A decrease in this statistics implies in fact that a larger number of banks have eased lending standards, which could correspond to a lower level of monitoring and hence to a decreased probability of repayment in our theoretical model.

A more direct measure of ex-ante loan risk is given by the internal risk rating assigned by banks to newly issued loans. In the US Terms of Business Lending Survey, available only from 1997-Q1 onwards, 400 banks report the volume of loans originated in the quarter prior to filling the survey, grouped by the internal risk rating. This rating varies between 1 and 5, with 5 being the maximum level of risk. Following Dell'Ariccia et al. [2014], we construct a weighted average loan risk series, using as weights the value of loans in each risk category. An increase in this risk measure could be caused either by worsened macroeconomic conditions, giving banks no other choice than making riskier loans, or by an active choice of the banks to extend credit to riskier borrowers on average.

We plot both measures of risk, together with the nominal risk-free interest rate, in figure 1. We can see that low levels of the monetary policy instrument tend to be associated with higher level of bank risk (lower or decreasing levels in the risk-taking measures). The two proxies for bank risk-taking behave differently only in 2008, when the net percentage of banks tightening standards displays a sharp increase. This suggests that in the aftermath of the financial crisis banks have tightened their standards mainly to ration demand without substantially changing the riskiness of their investments.

³We perform a qualitative model evaluation based on the comparison between the empirical impulse responses and the simulated ones, from the theoretical model. For further references on impulse-response based model evaluation we refer to Canova [2002].

Figure 1: **Bank risk taking and nominal interest rate**



Note: Both risk measures (solid blue lines, left axes) are defined such that a decrease can be associated to a higher risk-taking behaviour of the banking sector. The nominal interest rate (dashed line, right axis) is the effective federal funds rate. While the weighted average loan risk pertains to the current quarter, the net % of banks tightening standards refers to the change in reported lending standards over the previous quarter.

3.2 Estimation and identification strategies

We estimate the reduced-form VARs using Bayesian methods over the full sample available. We make real output and real loans per capita stationary by taking deviations from a linear trend. The net percentage of banks tightening standards is transformed so that it takes values between 0 and 1. We use a Natural-Conjugate prior, calibrated through a training sample of 10 years⁴. In the case of the weighted average loan risk, available only for a shorter time span, we form the training-sample prior using the alternative risk measure. Information criteria select a lag length of 2 or 1, and we experiment with both specifications.

We identify an unexpected monetary policy shock by using a set of sign restrictions that do not depend on the specificities of our theoretical model, but are instead robust across a variety of general-equilibrium models. In particular, we assume that an expansionary monetary policy shock decreases the nominal risk-free interest rate, and could decrease inflation and output, both at the time of the shock and in the quarter immediately after, as summarised in table 1. At the same time we identify a productivity shock, the other source of uncertainty present in our theoretical model, by assuming that an unexpected increase in productivity raises output and could cause a fall in both inflation and in the interest rate. This last response follows the assumption that the central bank policy rule reacts to inflation. In addition, note that the reaction of inflation allows for the separate identification of the two shocks.

As a robustness check, we apply a recursive identification scheme with two different variable orderings. While output and inflation are ordered always before the nominal interest rate, as common in the literature, the position

⁴Results using a Minnesota prior are discussed in Section 5.3.

Table 1: **Sign restriction identification scheme:** Restrictions are assumed to hold on impact and on the following period.

SHOCK	variables		
	y	π	R
MONETARY POLICY SHOCK	≥ 0	≥ 0	< 0
TOTAL FACTOR PRODUCTIVITY SHOCK	> 0	< 0	≤ 0

of risk and of the nominal interest rate vary. In the first exercise we order risk last, consistent with our theoretical model. The assumption is that banks take into consideration the level of the real interest rate for their investment decisions, but the monetary authority does not consider bank risk while setting the level of its policy instrument. As a second exercise we invert the ordering of the last two variables, and find similar conclusions.

3.3 Structural BVAR results

The core mechanism: The response of bank asset risk to an expansionary monetary policy shock in the core BVAR specification is shown in figures 2 and 3. An unexpected decrease in the monetary policy interest rate is followed by a macroeconomic expansion, with output and inflation increasing for about four years, and by a persistent increase in risk (q , the safety decreasing). This result is consistent across the definition of bank asset risk, with the only caveat that the reaction of the average loan risk rating is not significant on impact, as figure 3 shows. These results provide evidence in favour of the existence of a risk-taking channel in the US: a fall in the nominal interest rate increases the number of banks that ease credit standards, and increases the risk rating the banks attach to the loans in their portfolio. An interesting feature of all results is that the reaction of risk is more prolonged than that of the nominal interest rate.

Adding banking-sector variables: To gauge the functioning of the risk-taking channel, we add a set of banking-sector variables to the core specification. The variables are added in turn, as the sample size available is short. We first analyse the reaction of bank funding costs, shown in the last rows of figures 4 and 5. While the return on deposits falls on impact, mirroring the behaviour of the nominal interest rate, the return on equity increases on impact, and then falls persistently. Figures 6 and 7 further shows that the return on bank loans decreases in an expansionary monetary policy shock.

Overall, an unexpected decrease in the monetary policy interest rate causes a decline in banks' loan revenues, as well in the cost of deposits, while both the risk indicator and the return of bank owners increase. These responses are compatible with the existence of a risk-taking channel⁵: in a low interest-rate environment banks seek to increase the return of bank owners by investing in riskier assets. After a brief discussion of the robustness of the empirical results, we discuss in the next Section a theoretical model that explains the stylised facts observed so far.

⁵See for instance Rajan [2005] or Dell'Ariccia et al. [2014].

Figure 2: Monetary policy shock on the net % of banks tightening standards: Annualised inflation; $p = 2 (AIC)$

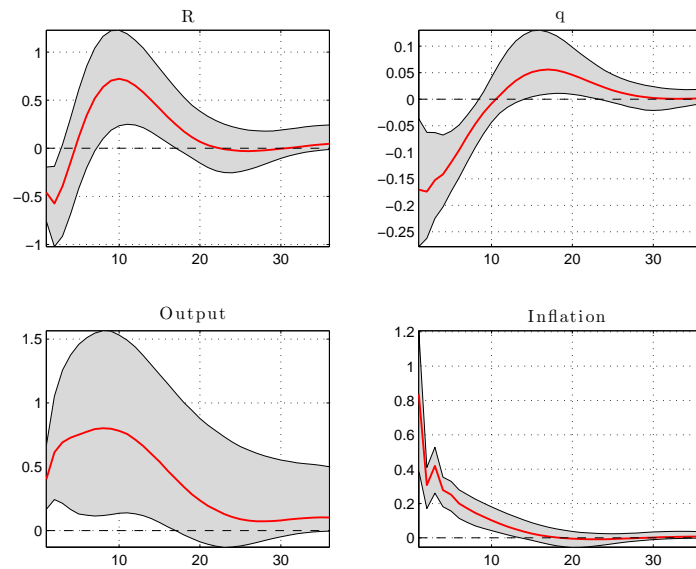
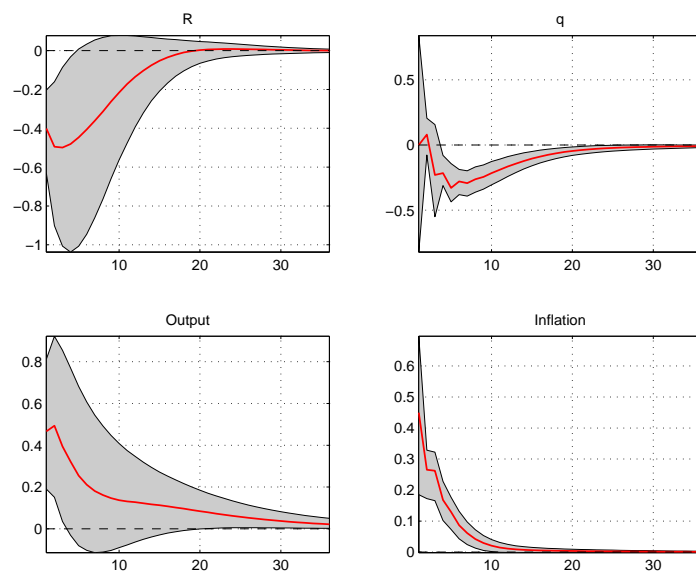


Figure 3: Monetary policy shock on the average loan risk rating: Annualised inflation; $p = 2 (AIC)$



Note: Impulse-response functions over a 9-year horizon, identified through the sign restriction scheme in Table 1. Estimation conducted using a 10-year training sample natural-conjugate prior. The error bands shown correspond to a 68% confidence interval and include sampling uncertainty.

Figure 4: Monetary policy shock on the cost of bank funding: Using tightening standards as a measure of risk; $p = 2 (AIC)$

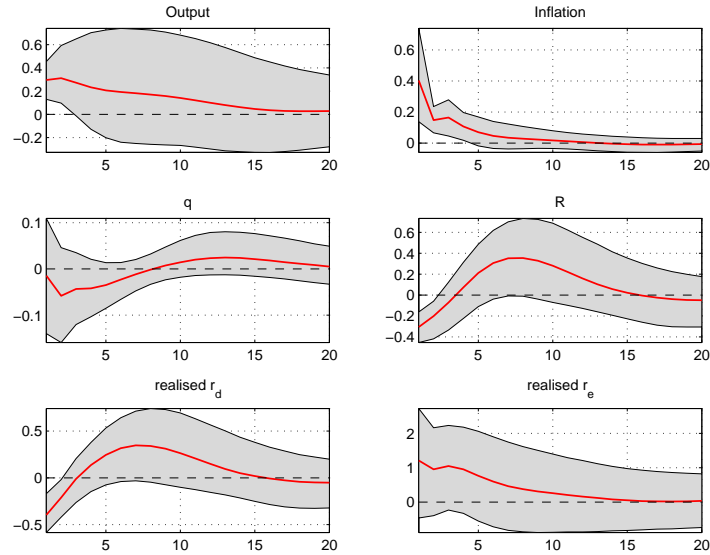
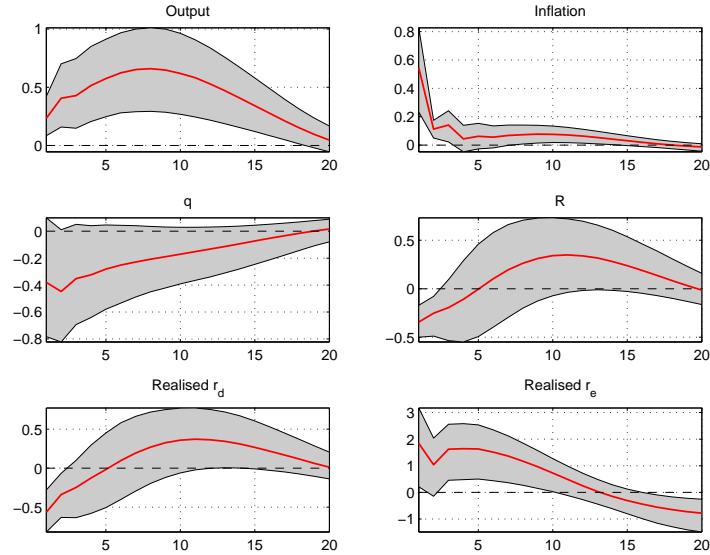


Figure 5: Monetary policy shock on the cost of bank funding: Using the loan risk rating as a measure of risk; $p = 2 (AIC)$



Note: Impulse-response functions over a 9-year horizon, identified through the sign restriction scheme in Table 1. Adding return on deposit and return on equity to the core model. Estimation conducted using a 10-year training sample Natural-conjugate prior. The error bands shown correspond to a 68% credible set and include sampling and rotation uncertainty.

Figure 6: Monetary policy shock on bank loan revenues: Using tightening standards as a measure of risk; $p = 2 (AIC)$

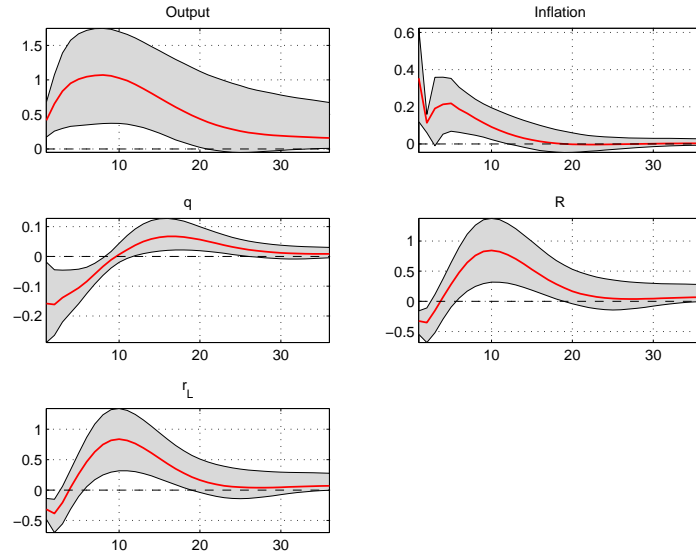
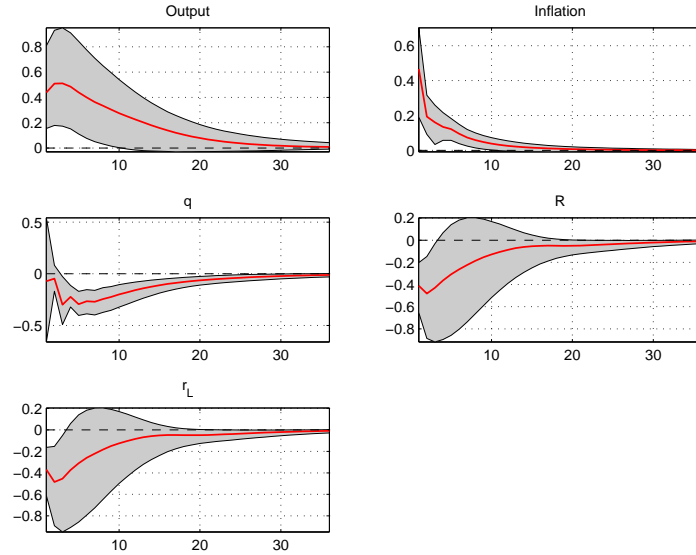


Figure 7: Monetary policy shock on bank loan revenues: Using the loan risk rating as a measure of risk; $p = 2 (AIC)$



Note: Impulse-response functions over a 9-year horizon, identified through the sign restriction scheme in Table 1. Adding return on loans to the core model. Estimation conducted using a 10-year training sample Natural-conjugate prior. The error bands shown correspond to a 68% credible set and include sampling and rotation uncertainty.

Robustness To assess the robustness of our results we have experimented with a different lag length, prior structure, and identification scheme. Choosing a lag length of 1, as selected by the BIC information criterion, does not significantly affect the results so far discussed. The impulse-responses tend to be more persistent, as shown in figures 10 and 11 in the Appendix, or more significant, as the model is less parametrized.

Results using a Minnesota prior are qualitatively similar for both measures of bank risk. The response of the bank asset risk is in fact always significant, albeit with a lag, as shown in figure 12. The only exception is in the specification with 2 lags and risk measured with the net percentage of banks tightening standards: in this case, shown in figure 13, the median response of risk is of the same sign but is insignificant.

A response of asset risk coherent with the existence of a risk-taking channel is moreover found when a monetary policy shock is identified recursively, with risk ordered last, as it can be seen in figure 14. Bank asset risk initially decreases and then significantly increases, following the propositions in our model. Changing the variable ordering by setting the monetary policy instrument last removes the initial incorrect response of bank asset risk, which tracks closely the movements in the nominal interest rate (see figure 15).

4 A dynamic New Keynesian model with a bank risk-taking channel

In this Section we build a general-equilibrium model that explains the stylised facts presented in the previous Section. We augment an otherwise standard New Keynesian model with an intermediation sector: competitive banks obtain funds from depositors and equity holders, which they lend to capital producers. Each bank faces a continuum of capital producers, each defined by a given risk-return characteristic. The risk choice of the representative bank is modelled analogously to Dell’Ariccia et al. [2014]. To assess the economy-wide effects of financial sector risk, we assume that the aggregate level of risk taking is affected by an exogenous shock. The other agents in the economy are households, intermediate goods producers, and final goods producers. We assume frictions in the price-setting ability of retailers, as well as capital adjustment costs. Three remaining shocks affect the economy: a productivity shock, a preference shock that changes the household’s marginal utility of consumption, and a mark-up shock, affecting the elasticity of demand and therefore prices.

4.1 Household

The representative household chooses consumption c_t and savings, as well as working hours L_t . Savings is possible through three instruments: government bonds s_t , bank deposits d_t , and bank equity e_t which must yield the same risk-adjusted expected return in equilibrium. The return on government bonds purchased today is safe and equal to the nominal interest rate R_{t-1} . As explained below, banks default with probability $1 - q_{t-1}$, in which case the return on both deposits and equity is zero. In case of repayment, deposits pay the nominal return $r_{d,t-1}$, fixed ex ante. Equity pays, if there is no default, the nominal return $r_{e,t}$, which is determined ex post, since equity holders are the residual income claimants and there is aggregate risk in the economy. While the aggregate risk cannot

be hedged, households are not exposed to default risk, since default is independently distributed and households diversify perfectly among a continuum of banks⁶. As we will see later there is an agency problem attached to equity. In order to have deposit contracts in equilibrium, we follow Dell’Ariccia et al. [2014] and assume a real cost of holding equity, ξ . This will mechanically yield an equity premium, i.e. the higher return on equity over deposits⁷. The net returns from deposits and equity are therefore: $q_{t-1}r_{t-1,d}$ and $q_{t-1} \cdot (r_{t,e} - \xi \cdot \pi_{t+1})$.

The problem of the household is to choose consumption, savings, and work in order to maximise its discounted lifetime utility:

$$\max_{d_t, e_t, s_t, c_t, L_t} E \left[\sum_{t=0}^{\infty} \beta^t \zeta_t \left(\frac{(c_t - b\bar{c}_{t-1})^{1-\sigma}}{1-\sigma} - \chi \frac{L_t^{1+\eta}}{1+\eta} \right) \right]. \quad (1)$$

subject to the budget constraint in real terms:

$$c_t + d_t + e_t + s_t + T_t = L_t w_t + d_{t-1} \frac{r_{d,t-1} q_{t-1}}{\pi} + e_{t-1} \left(\frac{r_{e,t} q_{t-1}}{\pi} - \xi \right) + s_{t-1} \frac{R_{t-1}^*}{\pi} + \Pi_t, \quad (2)$$

where π is the inflation rate, while T and Π are respectively taxes and profits from firm ownership, expressed in real terms. We assume that in each period a preference shock ζ_t shifts the marginal utility of consumption, defined as: $u_c(c_t) = \zeta_t (c_t - b\bar{c}_{t-1})^{-\sigma}$. The shock ζ_t evolves according to the following autoregressive process: $\log \zeta_t = \rho_\zeta \log \zeta_{t-1} + \sigma_\zeta \varepsilon_{\zeta,t}$, with $\varepsilon_{\zeta,t} \sim i.i.d. N(0, 1)$.

From the first order conditions with respect to consumption and savings we obtain the two no arbitrage conditions:

$$E[u_c(c_{t+1})r_{d,t}] = \frac{E[u_c(c_{t+1})]R_t}{q_t}, \quad (3)$$

$$E[u_c(c_{t+1})r_{e,t}] = \frac{E[u_c(c_{t+1})](R_t + \xi)}{q_t}. \quad (4)$$

The first order condition for consumption is the usual Euler equation:

$$u_c(c_t) = R_t \beta E(u_c(c_{t+1})), \quad (5)$$

and the labour decision is given by:

$$\chi L_t^\eta = u_c(c_t) \frac{w_t}{p_t}. \quad (6)$$

⁶This is a simplifying assumption that we want to relax in future work.

⁷Since the aim of this paper is not to explain this premium we choose this simple modelling device.

4.2 Final goods producer

The problems faced by intermediate and final good producers are standard: we discuss them briefly and refer to the modelling in Smets and Wouters [2003] for further details.

The final good producer assembles a continuum of intermediate goods, according to the following production function:

$$y_t = \left(\int_0^1 y_{it}^{1/(1+\lambda_{p,t})} di \right)^{1+\lambda_{p,t}},$$

where $\lambda_{p,t}$ is a random variable whose innovations give rise to a time-varying mark-up. In particular, the posited process is: $\log \lambda_{p,t} = (1 - \rho_{\lambda_p}) \log \lambda_p + \rho_{\lambda_p} \log \lambda_{p,t-1} + \sigma_{\lambda_p} \varepsilon_t^p$. This agent maximises the profit associated to the above production function competitively, i.e. taking input prices p_{it} and output prices p_t as given.

4.3 Intermediate goods producers

There is a continuum of firms producing a continuum of varieties using capital K_{it} and labor L_{it} as inputs. The production function is Cobb-Douglas:

$$y_{it} = A_t K_{it}^\alpha L_{it}^{1-\alpha},$$

and is affected by a total factor productivity shock A_t , which is persistent with log normal innovations; i.e. that: $\log A_t = \rho \log A_{t-1} + \varepsilon_{A,t}$ with $\varepsilon_t^A \sim i.i.d.N(0, \sigma_A^2)$.

Firms use their monopolistic power to set prices. Yet, as in Calvo (1988) they can only reset their prices each period with probability λ .

4.4 Capital producers

In this economy, capital is produced a continuum of capital producers, who get a loan l_t from the bank at $t - 1$ and transforms that into capital at t , which is then leased to the firm. The leasing contract includes maintenance, therefore capital producers have to also pay maintenance costs in t . Their technology is stochastic: with some probability capital is produced, else none.

$$f(l_t) = K_{t+1} = \begin{cases} \omega l_t & \text{with probability } q \\ 0 & \text{else} \end{cases}$$

Capital producers differ in the safeness of their technology q . The safer technology has higher maintenance costs (real maintenance cost per unit capital is $\frac{c}{2\omega}q$). For each value of $q \in [0, 1]$ there exists a continuum. While they will all request loans from the banks, the banks will choose exactly one type of capital producer q_t each period. The other capital producers remain idle for that period.

Given the choice q_t by the law of large numbers we get the law of motion of capital as follows:

$$K_{t+1} = q_t \omega l_t \quad (7)$$

Since the capital producers are competitive and have a linear technology they make no profit, but they return all their net cash flow to the bank. So the banks real return (conditional on no default) per loan is

$$r_{l,t} = \omega (r_{k,t} + (1 - \delta)) - \frac{c}{2} q_{t-1} \quad (8)$$

The motivation behind this unusual capital production technology is very simple: The higher the risk (the lower the q_{t-1}), the lower the return on capital. Note that you can reinterpret the leasing story in many ways: You can as well imagine that cost paid at the second period is some kind of staggered production cost. Instead of assuming maintenance cost paid by the capital producers, you could assume that the capital produced at higher risk is more effective for production at the firm.

4.5 The Bank

Following Dell'Ariccia et al. [2014] the economy is populated by a continuum of identical banks, which raise deposits and equity from the household to finance one period loans to capital producers. It is convenient to think of the banks problem as two stages.

First the bank raises funds: d_t units of consumption good through deposits and e_t through equity. She promises the depositors the safe return $r_{d,t}$. The rest of its cashflow tomorrow will be paid out to the equity holders, who will receive $r_{e,t+1}$ per unit of equity. Since there is aggregate risk, $r_{e,t+1}$ is ex-ante uncertain.

Second, the bank invests these funds $e_t + d_t$ into the capital producers. Each bank can only invest into one capital producer. This means that in case the capital producer fails, the bank will default on both its equity and deposit providers. But it can choose the risk characteristic q_t of the capital producer it invests into.

Three assumptions make the banks choice problem interesting: We assume that equity providers control the bank, are protected by limited liability and cannot commit in stage one which risk choice to make at stage two. This gives rise to an agency problem that drives a wedge between the ex ante optimal and the chosen risk level and will ultimately make the banks risk choice depend on the interest rate.

Before we solve the banks problem we need to introduce some notation. The banks real excess profit per loan (i.e. its cashflow net of funding costs) in period $t + 1$ is

$$r_{l,t+1} - \frac{r_{e,t+1}}{\pi_{t+1}} k_t - \frac{r_{d,t}}{\pi_t} (1 - k_t)$$

where we have used k_t to denote the equity ratio e_t/l_t . Using the loan return schedule (8) we get

$$\omega r_{k,t+1} + \omega(1 - \delta) - \frac{r_{e,t+1}}{\pi_{t+1}} k_t - \frac{r_{d,t}}{\pi_t} (1 - k_t)$$

Since the share holders control the bank, the bank maximises the utility of shareholders net of their opportunity costs, so the banks target function is:

$$\beta E \left[u_c(c_{t+1}) q_t \left(\omega r_{k,t+1} + \omega(1 - \delta) - \frac{c}{2} q_t - \frac{r_{d,t}}{\pi_{t+1}} (1 - k_t) - \frac{r_{e,t+1}}{\pi_{t+1}} k_t \right) l_t \right]$$

Note that the bank uses the households marginal utility to value payouts and disregards the case of default, when equity providers return is 0 due to limited liability.

To make notation more tractable we define:

$$\tilde{r}_{l,t} = E [u_c(c_{t+1}) (\omega r_{k,t+1} + \omega(1 - \delta))]$$

$$\tilde{c}_t = E \left[u_c(c_{t+1}) \frac{c}{2} \right]$$

$$\tilde{r}_{d,t} = E \left[u_c(c_{t+1}) \frac{r_{d,t}}{\pi_{t+1}} \right]$$

$$\tilde{r}_{e,t} = E \left[u_c(c_{t+1}) \frac{r_{e,t+1}}{\pi_{t+1}} \right]$$

$$\tilde{R}_t = E \left[u_c(c_{t+1}) \frac{R_{t+1}}{\pi_{t+1}} \right]$$

$$\tilde{\xi}_t = \xi E [u_c(c_{t+1})]$$

Using these definitions we can write the banks target function as

$$\left(q_t \tilde{r}_{l,t} - \frac{\tilde{c}_t}{2} q_t^2 - \tilde{r}_{d,t} (1 - k_t) - \tilde{r}_{e,t} k_t \right) l_t$$

and, for later use, the households no arbitrage conditions as

$$\tilde{r}_{d,t} = \frac{\tilde{R}_t}{q_t} \tag{9}$$

$$\tilde{r}_{e,t} = \frac{\tilde{R}_t + \tilde{\xi}_t}{q_t} \tag{10}$$

Let us now solve the banks problem.

4.5.1 Second-stage problem:

At the second stage the bank has already raised $e_t + d_t$ funds and now needs to choose the risk characteristic of her investment q_t such that equity holders utility is maximised. As already mentioned, we assume that the bank cannot write contracts conditional on q_t with the depositors at stage one, since q_t is not observable to them. Therefore at the second stage the bank takes the deposit rate as given. Furthermore, since the capital structure is already determined, maximising the excess profit coincides with and maximising the profit of equity holders.

So the banks problem is

$$\max_{q_t} q_t \tilde{r}_{l,t} - \frac{\tilde{c}_t}{2} q_t^2 - \tilde{r}_{d,t}(1 - k_t)$$

Solving with respect to q_t yields the following first order condition:

$$q_t = \frac{\tilde{r}_{k,t} - \tilde{r}_{d,t}(1 - k_t)}{\tilde{c}_t}$$

At the point of writing the deposit contract in stage one, depositors anticipate the bank's choices in stage two and therefore the households no arbitrage condition (9) must hold in equilibrium.⁸ Using this equation we can derive the optimal q_t as a function of k_t and $\tilde{r}_{k,t}$.

$$\hat{q}_t = \frac{1}{2c} \left(\tilde{r}_{l,t} + \sqrt{\tilde{r}_{l,t}^2 - 4c\tilde{R}_t(1 - k_t)} \right)$$

4.5.2 First-stage problem:

We can now solve the first stage problem: the choice of the capital structure k_t . Now bankers maximise their excess profits, anticipating the q_t that will be chosen at the second stage given the k_t now chosen:

$$\max_{k_t} \beta \left(\hat{q}_t \tilde{r}_{l,t} - \frac{\tilde{c}_t}{2} \hat{q}_t^2 - \tilde{r}_{d,t}(1 - k_t) - \tilde{r}_{e,t} k_t \right) l_t$$

Plugging in the no-arbitrage condition for depositors (9) and equity providers (10) we get:

$$\max_{k_t} \beta \left(\hat{q}_t \tilde{r}_{k,t} - \frac{\tilde{c}_t}{2} (\hat{q}_t)^2 - \tilde{R}_t - \tilde{\xi}_t k_t \right) ,$$

from which we obtain the first order condition:

$$\frac{\partial \hat{q}_t}{\partial k_t} \tilde{r}_{k,t} - \tilde{\xi}_t - \frac{\tilde{c}_t}{2} \frac{\partial \hat{q}_t^2}{\partial k_t} = 0 .$$

⁸That the bank does not consider this as a constraint of its maximisation problem is what yields the agency problem in this model.

which can be solved for k_t as:

$$k_t = 1 - \tilde{r}_{k,t}^2 \frac{\tilde{\xi}_t (\tilde{\xi}_t + \tilde{R}_t)}{\tilde{c}_t \tilde{R}_t (2\tilde{\xi}_t + \tilde{R}_t)^2} .$$

This concludes the banks choice problem. To determine l_t we use the fact that bank must in equilibrium expect not to make any profit, since they are perfectly competitive and operate a technology linear in l_t . In the presence of uncertainty, we focus on the case that they make no excess profit under any future state of the world.

$$\hat{q}_t(\hat{k}_t) \left[r_{l,t+1}(A_{t+1}) - r_{d,t}(1 - \hat{k}_t) - r_{e,t+1}(A_{t+1})\hat{k}_t \right] - \frac{c}{2}\hat{q}_t^2 = 0 .$$

Combining this condition with the optimality conditions of the second stage, we can derive analytical expressions for leverage k_t , riskiness q_t and the expected rate of return:

$$k_t = \frac{\tilde{R}_t}{\tilde{R}_t + 2\tilde{\xi}_t} \tag{11}$$

$$q_t = \sqrt{\frac{\tilde{R}_t 2(\tilde{R}_t + \tilde{\xi}_t)}{\tilde{c}_t [\tilde{R}_t + 2\tilde{\xi}_t]}} \tag{12}$$

$$\tilde{r}_{k,t} = \sqrt{\frac{2\tilde{c}_t \tilde{R}_t (\tilde{R}_t + 2\tilde{\xi}_t)}{\tilde{R}_t + \tilde{\xi}_t}}$$

Note that the riskiness of the bank $(1 - q_t)$ decreases in the safe interest real interest rate $\frac{R_{t+1}}{\pi_{t+1}}$ ⁹, as does the equity ratio k_t .

These close-form expressions also exemplify the three driving forces behind the posited risk-taking channel. On one hand, a lower risk-free interest rate decreases the rate of return on loans: this decreases the benefits of a safer investments, conditional on repayment. This induces banks to adopt a more profitable but riskier technology. On the other hand, the lower risk-free rate reduces the cost of funding, leaving more resources available to the bank's owner: this force acts in opposition to the first one and induces banks to adopt a safer investment technology. There is a final force: a lower risk-free interest rate eases the agency problem. As a result banks shift from equity to deposits: they internalise less the consequences of the risk decision, choosing a higher risk-return loan portfolio. The first and third effect predominate the second and the overall effect of a monetary expansion is to induce banks to acquire more risk.

⁹At least up to a first order approximation, when the marginal utility terms contained in the squiggle variables cancel out.

4.6 Central bank

Following the literature, we assume that the central bank follows a nominal interest rate rule, targeting inflation and output deviations from the steady state:

$$R_t = R_{t-1}^{\rho_R} \left[R^* \left(\frac{\pi_t}{\pi_{ss}} \right)^{\phi_1} \left(\frac{y_t}{y_{ss}} \right)^{\phi_2} \right]^{1-\rho_R} e^{\sigma_R \varepsilon_t^R}, \quad (13)$$

where ρ_R is a smoothing parameter, $R^* = \frac{1}{\beta}$ is the steady state nominal interest rate, and $\varepsilon_{R,t}$ is an i.i.d. monetary policy shock.

In addition, the central bank controls the supply of government bonds, which is set to zero for simplicity ($s_t = 0$), implying zero transfers through the budget constraint:

$$s_{t-1} R_{t-1} = s_t + T_t. \quad (14)$$

4.7 Equilibrium

The model we have outlined defines a system of 27 equations that determine 27 unknowns $A, K, L, y, l, c, q, k, d, e, s, T, r_k, r_d, r_e, R, w, mc, \pi, \tilde{\pi}, \Pi, g, h, v, \tilde{c}, \tilde{\xi}, \tilde{R}$.

Note that in this brief description of the model we have omitted the equations of the firm sectors, where we introduce the variables $mc, \tilde{\pi}, g, h, v$.

4.8 The risk-taking channel of monetary policy

We have developed a simple general-equilibrium model, based on the banking model of Dell’Ariccia et al. [2014], in which expansionary monetary policy induces the banking sector to select borrowers with a higher risk profile. In particular the bank can choose between projects with different risk-return characteristics. An agency problem between the depositors and the equity holders arises, since the latter cannot commit to a certain risk choice but are protected by limited liability. A lower risk-free interest rate reduces both the cost of bank funding, and the return on loans. In this setting, this has two opposite effects on the bank’s optimal risk choice. On one hand, a lower rate of return on loans reduces the bank’s revenue conditional on repayment, i.e. the upside potential, thus leading the bank to choose a riskier but potentially more profitable investment strategy. On the other hand, a lower cost of deposits increases the net return that can be paid to equity holders in case of repayment. This increases the upside potential and will induce banks to choose safer investments. In our model the first effect, the interest rate pass-through effect, dominates in equilibrium: thus, a lower level of the monetary policy interest rate and a lower return on loans will induce banks to choose a riskier loan portfolio, with a higher net return in case of repayment.

A graphical representation of the model’s response¹⁰ to an expansionary monetary policy shock is provided

¹⁰The model is solved using a first order approximation. We calibrate the parameters by using the posterior mean of the Del Negro

in figures 8 and 9. The figures show that the theoretical model posits a reaction of the economy to a monetary expansion that resembles what is observed in the data. The model fails to capture just the persistence of the responses, in particular of output, of the return on equity, and of risk-taking, which follows closely the pattern of the nominal interest rate.

5 Conclusions

The recent financial crisis has highlighted the importance of monitoring the level of risk to which the financial sector is exposed. One of the factors that can influence the risk-taking behaviour of financial intermediaries is the level of the risk-free interest rate, and therefore the stance of monetary policy. In this paper we extend the model of Dell’Ariccia et al. [2014] and build a general-equilibrium model where low risk-free interest rates affect banks’ revenues and funding costs, inducing them to extend credit to riskier borrowers. In particular, an expansionary monetary policy shock has two contrasting effects on the bank’s risk-taking decision. On one hand, a lower risk-free rate decreases the return on loans and therefore the benefits of a safe investment, conditional on repayment. On the other hand, expansionary monetary policy reduces the cost of funding, and in particular of deposits, increasing the resources available to the bank’s owner and the incentive to adopt a safe investment strategy. The first force predominates and the overall effect of an expansionary monetary policy is to induce banks to choose a riskier loan portfolio.

As a second contribution, we provide empirical evidence on the existence of a risk-taking channel in the US, by estimating a structural BVAR, identified through robust sign restrictions. Results suggest that an unexpected fall in the nominal risk-free interest rate decreases both banks’ loan revenues and the cost of bank funding, causing a persistent increase in bank asset risk. In addition, return on equity increases contemporaneously and subsequently falls, as in the model. These conclusions, robust to alternative identification and estimation procedures, are compatible with the monetary policy transmission mechanism posited in the theoretical model. Nevertheless, the model fails to capture the persistent response of banking-sector variables observed in the data. We therefore propose to modify the theoretical model so as to introduce persistence in the response of the bank asset risk choice, and of the return on equity. Such modifications would in fact enhance the plausibility of the model’s implication, making it a suitable tool for policy evaluation.

et al. [2005] model estimated on US data or, in the case of the banking sector variables, the calibration values of Dell’Ariccia et al. [2014]. The model impulse responses are obtained by simulating the data and estimating a BVAR as in the empirical Section.

Figure 8: Theoretical responses to an expansionary monetary policy shock:

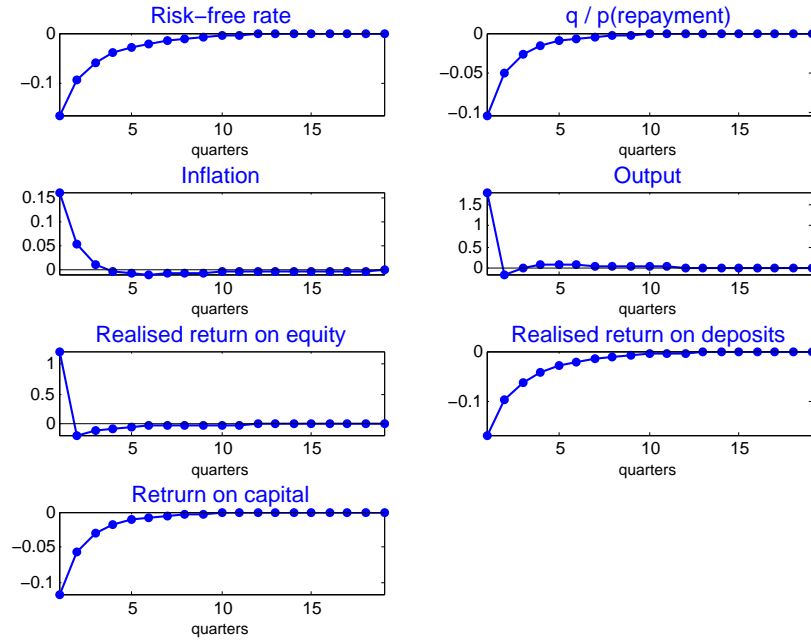
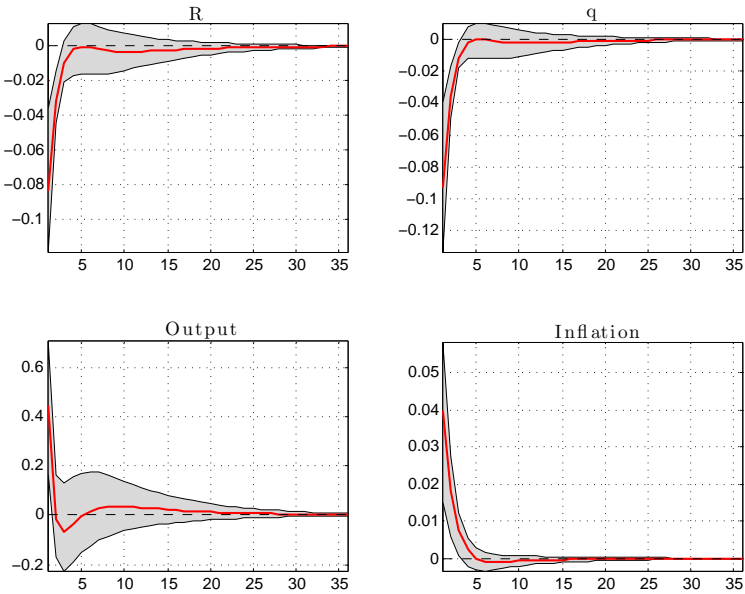


Figure 9: Simulated responses to an expansionary monetary policy shock:



Note: Theoretical and simulated impulse-response functions. Periods refer to quarters. R is the nominal interest rate, q is the safety of the bank portfolio, π_t is the inflation rate, y is aggregate output, q_{re} and q_{rd} are the realised return on equity and on deposits and l is the quantity of loans.

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Appendix B: Additional Tables and Figures

Figure 10: Monetary policy shock on the net % of banks tightening standards: Annualised inflation; $p = 1$ (*BIC*)

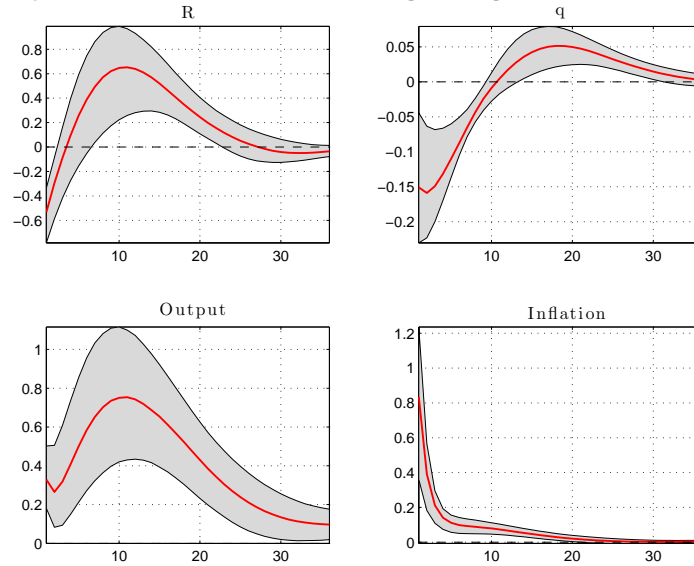
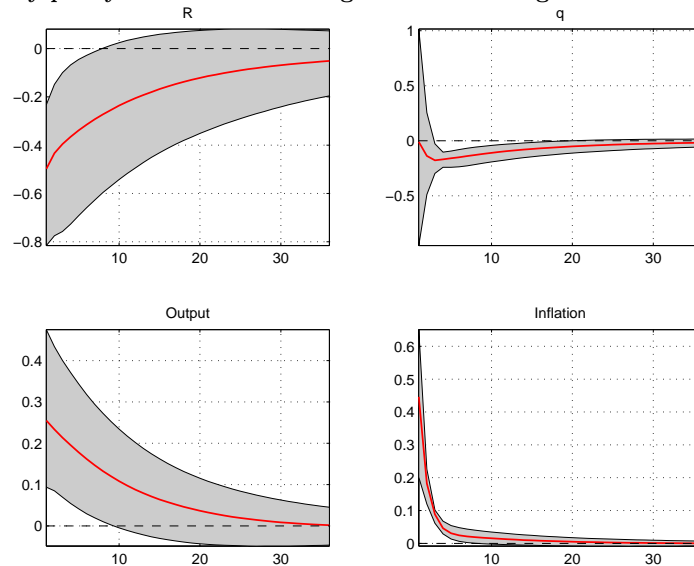


Figure 11: Monetary policy shock on the average loan risk rating: Annualised inflation; $p = 1$ (*BIC*)



Note: Impulse-response functions over a 9-year horizon, identified through the sign restriction scheme in Table 1. Estimation conducted using a 10-year training sample natural-conjugate prior. The error bands shown correspond to a 68% credible set and include sampling and rotation uncertainty.

Figure 12: **Using a different prior:** Monetary policy shock on the net % of banks tightening standards; $p = 1$ (*BIC*)

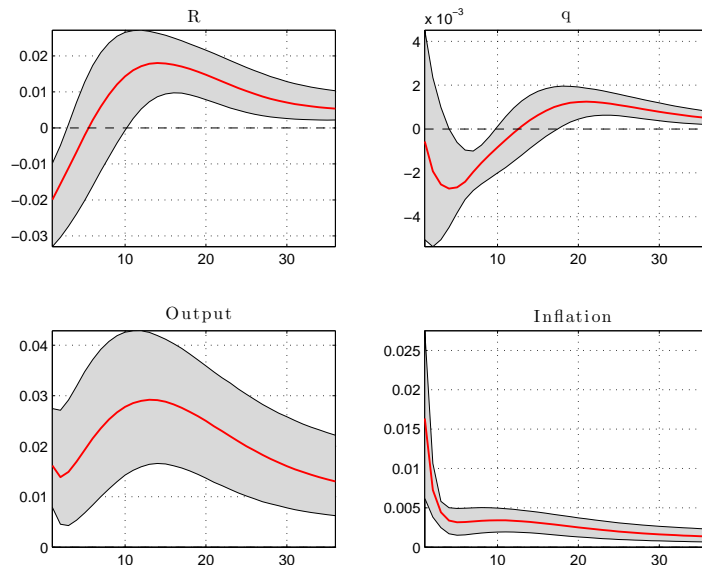
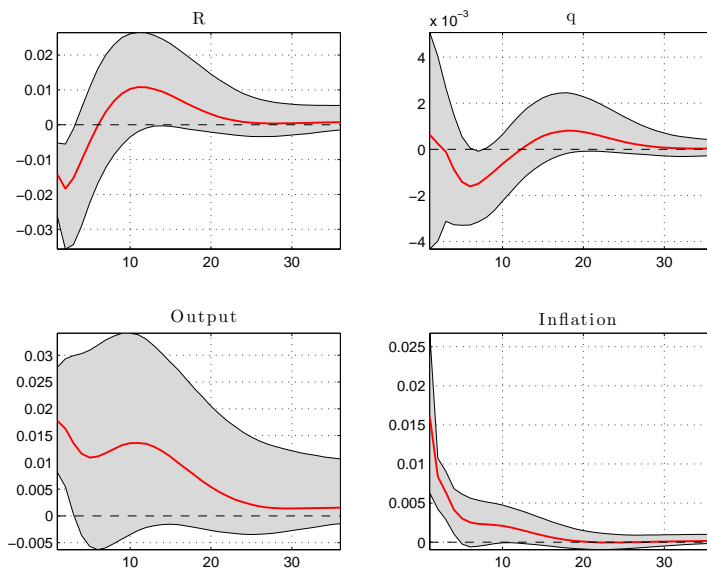


Figure 13: **Using a different prior:** Monetary policy shock on the net % of banks tightening standards; $p = 2$, (*AIC*)



Note: Impulse-response functions over a 9-year horizon, identified through the sign restriction scheme in Table 1. Estimation conducted using a 10-year training sample Minnesota prior. The error bands shown correspond to a 68% credible set and include sampling and rotation uncertainty.

Figure 14: **Recursive identification scheme results:** Federal funds rate ordered last; $p = 2$ (*AIC*)

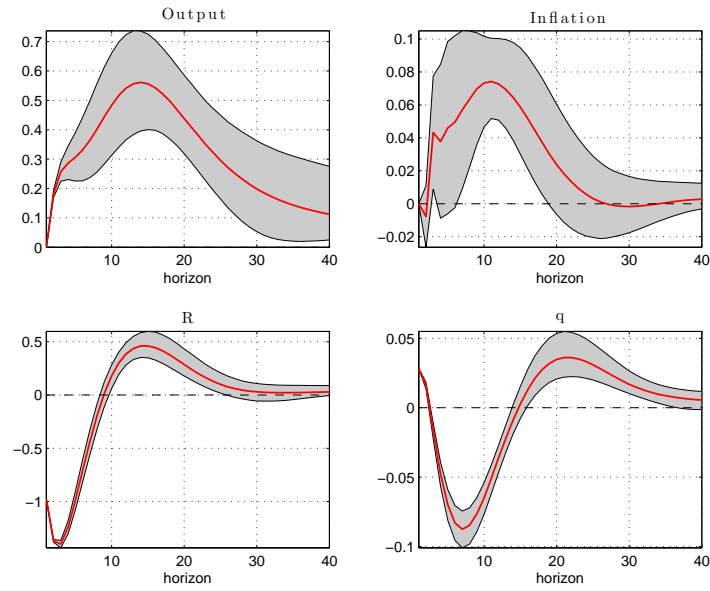
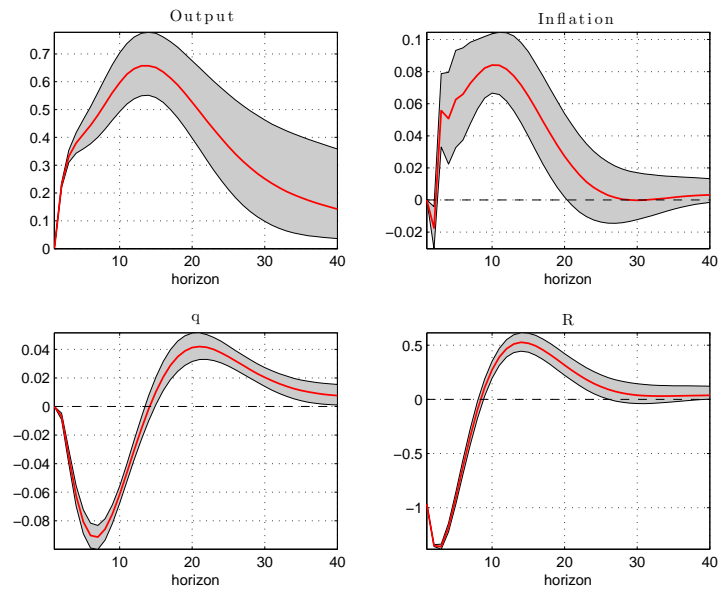


Figure 15: **Recursive identification scheme results:** Risk ordered last; $p = 2$ (*AIC*)



Note: Recursive identification scheme results: risk measured as the net % of banks tightening standards. The error bands shown correspond to a 68% credible set and include sampling uncertainty.

Appendix A: Data description

SYMBOL	SERIES	MNEMONIC	UNIT	SOURCE
y	GDP	GDP	BN. USD	FRED
P	GDP DEFLATOR	GDPDEF	INDEX 2009 = 100	FRED
R	EFFECTIVE FEDERAL FUNDS RATE	FEDFUNDS	%	FRED
q_1	NET % OF BANKS TIGHTENING STANDARDS	DRTSCLM	%	FRED
q_2	AVERAGE WEIGHTED LOAN RISK		%	BOARD OF GOVERNORS OF THE F.R.S.
L	LOANS	TOTAL LOANS	TR. USD	BOARD OF GOVERNORS OF THE F.R.S.
r_L	RETURN ON LOANS	MPRIME	%	FRED
r_E	RETURN ON EQUITY	USROE	%	FRED
r_D	3M RETURN ON CERTIFICATE OF DEPOSITS	CD3M	%	FRED
N	POPULATION	CNP160V	THOUSANDS	FRED

Note: GDP and Loans are deflated using the GDP deflator and taken in per capita terms using the population series. Both variables are detrended using a linear trend. Inflation is measured as $400 \cdot (\log P_t - \log P_{t-1})$. The estimation sample starts in 1990-Q2 or in 1997Q2 depending on whether bank risk is measured with q_1 or q_2 , and ends in 2013-Q3. The series for loans is available only from 1991-Q1.