BRUEGEL WORKING PAPER 2010/00

MONETARY POLICY AND RISK TAKING

IGNAZIO ANGELONI*, ESTER FAIA** AND MARCO LO DUCA†

Highlights

- The financial and economic crisis has taught central banks a lesson. They were previously primarily concerned with maintaining price stability, but the crisis has produced evidence to show that monetary policy can contribute to the development (or the mitigation) of systemic risk in the financial sector. Monetary policy therefore needs to take financial stability implications into account, and the macroeconomic implications of bank supervision and regulation must also be considered.

- It is therefore important to understand the linkages between financial risk, monetary policy and the business cycle. This paper considers the thinking to date on risk taking in monetary policy, presents comparative evidence for the euro area and the United States, and interprets the evidence using a macro dynamic stochastic general equilibrium model.

- This approach produces three preliminary conclusions: central banks' monetary policy approaches affect, with time lags, the propensity of financial markets and banks to assume risk; it is possible to take account of these effects through macroeconomic models that embody optimising agents with limited information and include explicitly banking and financial sectors; and there is some indication that the modelling done in the paper can be used as the basis for predicting the relationship between monetary policy and the effect of risk on macroeconomic variables, though this area needs considerable further research.

* Visiting Scholar at Bruegel and advisor to the Executive Board of the European Central Bank.
** Goethe University Frankfurt, Kiel IfW and CEPREMAP.
† European Central Bank.

FEBRUARY 2010

Monetary Policy and Risk Taking*

Ignazio Angeloni
European Central Bank and BRUEGEL

Ester Faia
Goethe University Frankfurt, CFS and Kiel IfW

Marco Lo Duca
European Central Bank

This draft: December 2011.

Abstract

We assess, through VAR evidence, the effects of monetary policy on banks' risk exposure and find the presence of a risk-taking channel. A model combining fragile banks prone to risk mis-incentives and credit constrained firms, whose collateral fluctuations generate a balance sheet channel, is used to rationalize the evidence. A monetary expansion increases bank leverage. With two consequences: on the one side this exacerbates risk exposure; on the other, the risk spiral depresses output, therefore dampening the conventional amplification effect of the financial accelerator.

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

*Correspondence to: Ignazio Angeloni, Kaiserstrasse 29, 60311 Frankfurt am Main, Germany, ignazio.angeloni@ecb.int; Ester Faia, Department of Money and Macro, Grüneburgplatz 1, Frankfurt am Main, Germany, faia@wiwi.uni-frankfurt.de; Marco lo Duca, Kaiserstrasse 29, 60311 Frankfurt am Main, Germany, marco.lo_duca@ecb.int. We thank seminar participants at EEA meetings 2010, the University of Maryland, the Bank of England and the Conference on Future Challenges for Economic Research at the Danish Ministry of Science for useful comments. The authors are the sole responsible for the content of the paper.

1 Introduction

Central banking no longer is what it used to be. Until 2007, central banks followed an 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 price change for 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: neither should central banks pursuing price stability 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 uncertainly on where responsibility really belongs; 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 supervision[1]. 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. The transmission of monetary policy seems more complex than was assumed earlier. 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 – specifically, a link between monetary condition and the propensity of agents to assume financial risk – puts the *single focus* tenet into question (see Eichengreen et al. [26]). But also the *assignment* argument would somehow be affected; if monetary policy can contribute to the formation

[1] See the classic survey of Goodhart and Schoenmaker [30].

(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, some voices from the 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 decisions[2].

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 some recent literature on the risk taking channel of monetary policy. Second, we present some new time series evidence. The evidence in the literature and that presented in this paper support the idea that monetary policy influences risk-taking in the banking sector via changes in its funding side. An expansionary monetary policy induces banks to choose a more leveraged and risky capital structure. Third, we lay out a macro model with banks to interpret this evidence. The model is standard except for the fact that it includes a banking sector, which, on the funding side, is exposed to endogenous bank runs (see Diamond and Rajan [24], [25], Allen and Gale [5], and more recently Angeloni and Faia [9]), while on the lending side it faces an asymmetric information problems with firms requiring external finance to undertake investment (Bernanke et al. [12]). More specifically, on the funding side, banks act as relationship lenders on behalf of outside financiers and raise funds through short term liabilities, which are subject to a service constraint, and capital. Within the contractual agreement stipulated between the bank and the outside investors, runs on short term liabilities arise endogenously as discipline device: despite this, a fall in the risk free rate (as triggered by expansionary monetary policy) induces banks to increase short term liabilities (which become cheaper), and the probability of a run on such liabilities occurring.

[2] Kashyap and Mishkin [33].

On the asset side, loans are granted to entrepreneurs to launch investment projects, financed partly with internal funds, partly by the intermediary and partly by corporate loans, whose return is subject to idiosyncratic shocks observable only by entrepreneurs. The bank can observe the shock ex post upon payment of a monitoring cost. The ensuing agency problem is solved through a costly state verification contract a' la Gale and Hellwig [29], as in the financial accelerator model.

The presence of the two contractual agreements allows us to consider both the entrepreneurs' balance sheet channel and a banks' risk taking channel. A fall in the policy rate, by increasing asset prices, brings about an increase in the value of both intermediaries' and entrepreneurs' balance sheet. The latter induces a decline in the premium firms pay on external finance, which generates an amplification of the transmission to aggregate demand and output. This is the standard financial acceleration mechanism. In addition, the fall in policy rate induces intermediaries to increase short term liabilities, hence their risk exposure (a risk taking channel)[3]. Bank risk generates resource costs, in terms of foregone output for early project liquidation and an expected loss on deposits: for this reason, in the medium run, output is generally lower than in a standard financial accelerator. This rich specification allows to examine the impact of monetary policy on both the lending and the funding behavior of banks, and to analyse how the interaction of the two sides affects the transmission to the real side of the economy.

The model is analyzed in comparison with two simpler benchmarks: the model by Angeloni and Faia ([9], henceforth AF), with banks but no financial accelerator, and the classic financial accelerator, without banks. We find that the model combining the two sources of risk contains a number of novel features concerning monetary transmission. Risks on the asset side and on the liability side of banks tend to move together and to reinforce each other: a fall in the policy rate induces more firms to require bank funding; the increased

[3]Importantly, notice that the traditional financial accelerator advances the opposite prediction for what concerns firms' risk: as the policy rate falls, the external finance premium declines; firms become more solvent and their default rates decline. In this respect, the effect of the monetary expansion is univocal. Our model shows that this can come along with banks which, by leveraging more, face higher run probability.

platform of investment projects, requiring funds, coupled with the cheaper cost of short term liabilities induces banks to increase leverage, therefore increasing the overall likelihood of a run. Since bank risk generates resource costs, the risk spiral depresses output, dampening the monetary policy transmission to the real economy. in our parameter configuration, the dampening effect reduces the potency of the transmission mechanism compared to both the conventional financial accelerator model and a model like AF, featuring only the bank funding risk.

So far, the literature has offered some examples of partial equilibrium static models featuring banks' risk taking: from the classic work of Allen and Gale [7], to, more recently, Acharya and Naqvi [2], Agur and Demertzis [3], Dell'Ariccia, Laeven and Marquez [34], De Nicolo' et al. [23]. Three features make our work different and particularly suitable to interpret macro evidence. First, the earlier papers focus on partial equilibrium banking and neglect the transmission of risk to the real economy[4]. Second, in those papers the interest rate is exogenous: accounting for the endogenous response of the monetary authority seems a natural step to interpret macro time series evidence. Third, not less importantly, the literature has focused on risk taking on the asset side of the bank balance sheet, while we explore also the interaction with the funding side.

The paper is organized as follows. In section 2 we recall some recent literature relevant to our problem. In section 3 we present new time-series evidence on the transmission of monetary policy on bank risk in the US. In section 4 we present our macro model. In section 5 we analyse the model, in two-steps: first we provide an intuition for the mechanics and interaction of the liability and the asset sides of the bank; second we look at two impulse responses, respectively to a monetary policy and a productivity shock. In doing so, we compare the properties of our model with those of the two simpler benchmarks described above. Finally, section 6 concludes.

[4] Allen and Gale's [7] model features a link with consumption.

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 monetary policy transmission. The classic 1995 survey by Mishkin, Taylor and others in the Journal of Economic Perspectives [36] hardly mentions bank and financial risks at all. 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 [10]), indicators of bank risk are actually used in the econometric estimates of the "lending channel", but only to quantify certain features of the banking sector that, taken as a given, may affect the strength of the transmission, not because monetary policy may itself influence those characteristics.

In a different context, however, other authors had stressed 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 [6] 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 [7], consists in the fact that aggregate credit developments in the economy are, at least partly, under the control of monetary authorities. Borio and Lowe [19], 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 economists at 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 [38] analyzed how the incentives structures in the financial system may induce asset allocation managers to assume more risk under persistently low interest rates. In a low interest rate environment, portfolio managers that are 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, leading to confidence crises and possible "sudden stops" of credit. Two are the implications for central banks: first, monetary policy should 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 destabilizing.

To help the subsequent analysis, it is useful to distinguish between two different channels through which risk-taking behavior 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 may have an incentive to shift the composition of their investments towards a riskier mix, either for the reasons explained by Rajan [38], or because the overall risk in the economy increases. A second channel runs via the structure of bank funding. An expansionary monetary policy may affect the composition of bank liabilities, altering the mix of capital and short term funding in favor of the latter. This channel operates in particular when short term rates are low and the yield curve upward sloping, as emphasised for example by Adrian and Shin [1]. Statistical and anecdotal information confirm 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 not only to more leveraged balance sheet structures, but also to more risky assets.

The empirical evidence on these transmission channels has grown fast in recent times. Two strands can be distinguished. A first one tried to identify effective leading indicators of financial crises. It has been found that, in a variety of different national contexts and historical periods, financial crises tend to be preceded by a recurrent set or economic developments (see Reinhardt and Rogoff, [40]). 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 [29], focusing on house price booms. This evidence, though not 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.

Two very recent papers tackle the issue more directly.

Maddaloni and Peydró Alcalde [35] 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. In particular, the questionnaires try to distinguish between supply related factors (i.e. linked to bank-specific conditions) and demand related ones (i.e. depending upon borrowers' conditions). The authors use a panel regression to link the survey results to alternative indicators of monetary policy. The proxy for monetary policy has consistently significant effects: a monetary expansion leads to lower credit standards, for corporate as well as personal loans. Moreover, the longer a given policy stance lasts, the more effect its seems to have.

Another recent paper (Altunbas et al. [8]) 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 a decrease of short term rates reduces overall bank risk in the short run but increases it over time. The immediate effect is attributed to the impact on outstanding loans; the delayed one to the fact that banks tend to engage subsequently in more risky lending (note, however, that this effect could also be due to more risky funding). A similar conclusion is reached by Jimenez et al. [32] in their analysis of a large sample of Spanish banks, using detailed credit register data.

3 Some time series evidence

In this section we report some time series evidence on the effect of monetary policy on bank risks, following the ideas illustrated in the previous section. The main purpose, besides adding new aggregate time series evidence to that already existing, which is mainly on micro-panel data, is to try to shed some light on the different channels through which monetary policy affects bank risk: funding behavior, lending behavior, or both, or neither.

We use a standard orthogonalized VAR model, with monthly US data over the period from January 1980 to September 2011. We adopt, with modifications, the specification used by Bloom [16] (see also Bloom et al. [17]). The VARs include a small set of variables characterizing the macro-economy, such as output and labor market performance (industrial production index, employment), inflation (CPI and PPI), and a measure of monetary policy (detrended Fed funds rate). To this basic specification we add a small set of proxies for bank risk[5]. In particular, we used three measures (more details on these and on the macro variables are in the Data Appendix):

A] a measure of bank *funding* risk, represented by the volume of bank "market funding" (bank funding net of capital and customer deposits) as a ratio to total bank assets. This is intended to measure that part of bank funding that is subject to roll-over risk, namely, uninsured funds carrying a non-contingent contractual return and hence potentially subject to sudden withdrawal if market confidence deteriorates.

B] a measure of bank *asset* risk, derived from the FED Survey of Terms of Business Lending; in particular, the variable used is the balance of answers to the question of wether

[5] The ordering is that adopted by Bloom, with the additional assumption that all shocks immediately influence the bank balance sheet. 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.

the bank conditions for commercial and industrial loans to large and medium enterprises had been tightened[6].

C] a measure of bank *overall* risk, represented by a realized volatility measure of daily returns on bank stocks[7].

The three measure are meant to identify possible channel of transmission of monetary policy to bank risk, the first to the liability side of banks, the second to the asset side, the third to banks as a whole (hence encompassing possible effects running through either the liability side, or the asset side, or both). In particular, we expect that, if there exist a "risk taking channel" of monetary policy running via the funding side, the proxies A and C should decline significantly when monetary policy is tightened. If instead a risk taking behavior exists only on the lending side, proxy B and C should show a significant decline. If no risk taking channel to banks exist, none should be significant.

Figure 1 shows the impulse responses of bank funding risk and of bank overall risk, respectively in the upper and lower panels, to an upward monetary policy shock (the measure of asset risk was never significant, and is not reported[8]). The effects are both significant, negative and protracted (the confidence band are calculated at 90 percent level). In particular, the proxy for bank funding risk (upper panel) reacts significantly on impact, builds up reaching a peak at around 2 quarters (remember that data are monthly) and then gradually phases out. The proxy for overall risk (lower panel) does nor react immediately, but shortly afterwards becomes significantly negative and reaches a peak at about the same lag. It is remarkable that, though the proxies are completely different in their statistical content, the profile is similar (though funding reacts first) and the peak is located at about the same time.

We conducted a checks to verify the robustness of our results. We first changed the de-

[6] This variable is available only at quarterly frequency, hence we estimated a quarterly version of the model.

[7] Specifically, we used the average of daily absolute returns of a bank stock price index over each month.

[8] Results for other variables are available on request.

finition and the measurement of our risk variables, replacing them with alternative proxies[9]; the results remained stable. Finally, we ran all estimates again on quarterly data; the results were stable, but significance was somewhat lower. Finally, in addition to the VARs we also calculated Granger causality tests. The results, not reported here, are consistent in spirit with the VAR results just described: we found evidence of causality from monetary policy shocks to the proxy for funding risk, while causality in the other direction was not detected.

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 endogenous 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 make portfolio decisions. In every period, a fraction γ of the household 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 and a fraction $(1-\varsigma)$ of entrepreneurs exit every period. To

[9] Concerning funding risk, the ratio of market funding to total assets was replaced by the ratio of interbank funding to total assets. As a measure of overall bank risk we alternatively used the expected default frequencies produced by Moody's KMV.

maintain the population 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 bonds[10] with intermediaries that they do not own. Due to the possibility of bank runs, the return on deposits is actually subject to a time-varying risk (details in Appendix 1)[11]. 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.

Households maximize the following discounted sum of utilities:

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

where C_t denotes aggregate consumption and N_t denotes labour hours. Households receive, on deposits, a gross nominal return R_t one period later. 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:

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

where T_t is lump sum taxation. Households choose the set of processes $\{C_t, Nt\}_{t=0}^{\infty}$ 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:

[10] Corporate bonds are assumed to be risk free and to have a return equal to the risk free rate on deposits, for simplicity. Based on the Harrison and Kreps [31] equivalence result we can omit corporate bonds from the budget constraint as their return can be expressed as a linear transformation of returns on demand deposits.

[11] If a run occurs the depositors are paid by the bank up to the realized banks' returns; the rest is covered by the government via lump sum taxations. Hence the default affects the resource constraint but not the households' budget constraint. To preserve the possibility of bank runs, it is sufficient to assume that the government covers the remaining losses only after the bank has defaulted and paid its fraction of realized returns.

$$\frac{W_t}{P_t} = -\frac{U_{n,t}}{U_{c,t}} \tag{3}$$

$$U_{c,t} = \beta E_t\{R_t U_{c,t+1}\} \tag{4}$$

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.

4.2 Intermediation sector

The intermediation sector collects funds from outside investors (demand depositors, holding short term liabilities subject to a service constraint, and bank capitalists) and allocates them to entrepreneurs, who undertake capital investment. Firms finance investment with bank lending, corporate bonds and internal funds. The returns to capital investment has a general aggregate component, represented by the marginal productivity of capital plus the capital gains obtained through the resale market. The intermediary (bank) is subject to two idiosyncratic shocks. The first, on the return of the project, is visible only to entrepreneurs: this creates an agency problem between the intermediary and the entrepreneurs, which is solved through a debt contractual agreement. The second, affecting the return on bank lending, is observable by the bank but not by its outside investors: this informational advantage creates an agency problem between the intermediary and the bank's external financiers. This second agency problem is solved through a contractual agreement between the bank and its outside investors. The presence of two shocks permits to distinguish between two different risks inherent in the intermediary's activity: one concerning the project being financed, the other regarding the balance sheet structure of the bank itself, specifically the composition of its funding between capital and deposit liabilities (or equivalently, its leverage).

To allow a tractable representation of the two agency problem, we consider an intermediary organized in two departments, a funding one and a lending one. The lending department is modeled by designing a standard debt contract (a' la Gale and Hellwig [29]) along the lines of the financial accelerator, while the funding department is modeled assuming that a "manager " determines the composition of bank liabilities so as to optimize the combined return of depositors and bank capitalists (along the lines of Angeloni and Faia [9], who apply the theory of Diamond and Rajan [24], [25]). In general equilibrium the two agency problems interact in characterizing the transmission of monetary policy in our model, as detailed below.

4.2.1 Bank Lending

The credit side is modelled as a standard financial accelerator (Bernanke et al. [12], Faia and Monacelli [28]). Entrepreneurs finance their capital, $Q_t K_{t+1}$, partly through internal funds, NW_{t+1}, and partly through external funds, EF_{t+1}.[12] The latter includes a fixed proportion $1-\xi$ of bank funds, L_{t+1}, while the rest is raised by issuing corporate bonds.

The investment projects are characterized by a return equal to $R^K_{t+1} Q_t K_{t+1}$, where R^K_{t+1}, Q_t and K_{t+1} are respectively the nominal return on capital, the price of capital and the stock of capital: their values are determined by the behavior of capital producers (see below). Project outcomes are subject to an idiosyncratic uncertainty, taking the form of a multiplicative random shock on expected returns. The shock ω is assumed to have a uniform density function $f(\omega)$, with support $[a,b]$; hence $\omega \in (a,b)$; $f(\omega) = \frac{1}{b-a}$; $E(\omega) = \frac{a+b}{2}$[13]. Therefore, the monetary return of an investment project financed at t is given by $\omega_{t+1} R^K_{t+1} Q_t K_{t+1}$[14]. Importantly, this shock is freely observed (ex-post) only by the entrepreneur: observability by the bank is subject to the payment of a proportional monitoring cost, μ. This informational assumption gives rise to an agency problem between the bank and the entrepreneurs.

[12] 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.

[13] Contractual optimality requires a shock distribution with a decreasing hazard rate. Such an assumption is compatible with several probabilistic structure (uniform, logistic, lognormal). We have chosen the uniform as this allows to obtain closed form solutions for the external finance premium.

[14] R^K_{t+1} therefore represents the expected average return with respect to the idiosyncratic shock ω_t.

The debt contract requires maximizing the expected returns to the entrepreneurs[15] subject to participation constraints for both, entrepreneurs and the intermediary.

The mechanism which guarantees incentive compatibility, namely that the firm does not mis-report the true return, is as follows. For all realization of ω_{t+1} for which the project return is high enough to guarantee loan repayment, the contract stipulates a non-contingent (with respect to the realization of ω_{t+1}) repayment schedule, R^{BF}_{t+1}, whose value is set equal to the minimum return for which repayment is possible. This guarantees that entrepreneurs do not have incentives to mis-report. Under the solvency states the entrepreneur retains the surplus, given by the difference between the actual realized return and the non contingent repayment schedule. In the no-solvency region, the bank acquires information on the true realized return by paying a monitoring cost and repossesses everything that is left (maximum recovery property).

In the dynamic contract, the threshold value, ϖ_{t+1}, above which the entrepreneur is able to repay, is determined by the following condition:

$$\varpi_{t+1} \equiv \frac{R^{BF}_{t+1} EF_{t+1}}{\omega_{t+1} R^{K}_{t+1} Q_t K_{t+1}} \tag{5}$$

which establishes the minimum value, ϖ_{t+1}, for which the unitary monetary return from holding a unit of capital, $\omega_{t+1} R^{K}_{t+1} Q_t$, falls short of the repayment schedule, $R^{BF}_{t+1} EF_{t+1}$. Being a zero profit condition, equation 5 also represents entrepreneurs' participation constraint: project expected returns should guarantee the existence of region with profits larger or equal to zero.

Given the above contractual agreement, for each nominal unit lent, the gross expected return to the lender is given by:

$$\Gamma(\varpi_{t+1}) \equiv \left(\int_a^{\varpi_{t+1}} \omega_{t+1} f(\omega_{t+1}) d\omega + \int_{\varpi_{t+1}}^b \varpi^j_{t+1} f(\omega_{t+1}) d\omega \right) \tag{6}$$

[15] As agents, entrepreneurs have the bargaining power.

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

$$M(\varpi_{t+1}) \equiv \mu \int_{a}^{\varpi_{t+1}} \omega_{t+1} f(\omega_{t+1}) d\omega \tag{7}$$

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

The entrepreneur's investment is financed by a mix of internal and external funds. On the external side, a fraction ξ is financed by funds intermediated by the bank, and the remaining part is financed through corporate debt sold to households. The expected returns on the two components of external finance are R_t^A and R_t, respectively. The first of these two returns is subject to an idiosyncratic shock, discussed in the next sub-section. The second is assumed to be equal to the contractual (risk free) rate on bank deposits, R_t.

The participation constraint for the lender establishes that its expected returns must not be inferior to the cost of funds:

$$\left[(1-\xi)R_t^A + \xi R_t\right](Q_t K_{t+1} - NW_{t+1}) \leq R_{t+1}^K Q_t K_{t+1} [\Gamma(\varpi_{t+1}) - \mu M(\varpi_{t+1})] \tag{8}$$

The lending contract establishes an optimal value for the amount of lending, EF_{t+1}, and the threshold, ϖ_{t+1}, which maximize the expected return to the entrepreneur subject to entrepreneurs' participation constraint, 5, and lenders' participation constraint, 8. Working out the analysis, one obtains an expression for the premium on external finance, $\rho(\varpi_{t+1})$, as follows

$$\rho(\varpi_{t+1}) = \frac{R_{t+1}^K}{[(1-\xi)R_t^A + \xi R_t]} = h(\varpi_{t+1}) \left(1 - \frac{NW_{t+1}}{Q_t K_{t+1}}\right) \tag{9}$$

where ϖ_{t+1} and μ are respectively the optimal 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 $\frac{NW_{t+1}}{Q_t K_{t+1}}$.

Lastly, we need to determine the evolution of the aggregate net worth. Entrepreneurs are finitely lived[16], with a probability of remaining in business next period equal to, ς. Next period net worth is given by the accumulated expected returns accruing to entrepreneurs who do not exit the market:

$$NW_{t+1} = \varsigma(1 - \Gamma(\varpi_{t+1}))Q_t R_t^k K_t \tag{10}$$

Rearranging and using 8 one can write this as:

$$NW_{t+1} = \varsigma R_t^K Q_{t-1} K_t - \varsigma \left\{ \left[(1-\xi) R_t^A + \xi R_t \right] + m_t \right\} (Q_{t-1} K_t - NW_t) \tag{11}$$

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.

4.2.2 Bank Funding

The funding department raises funds from outside investors, depositors and banks capitalists, and allocates them to the lending department. Total funds, given by the sum of deposits (D_t) and bank capital, (BK_t), equal bank lending, which in turn equals the external finance by firms after subtracting the part financed on the bond market (share ξ)[17]:

$$L_t = (1-\xi)(Q_{t-1} K_t - NW_t) = D_t + BK_t \tag{12}$$

The liability structure of the bank, measured by the deposit share, $d_t = \frac{D_t}{L_t}$[18], is determined by a bank liability manager on behalf of the external financiers (depositors and bank capitalists). What we call, for terminological simplicity, deposits are not traditional retail deposits, which usually are nearly fully insured; they are uninsured short term funding instruments (for example, asset-backed securities, or repos). These instruments yield a contractual non-contingent return set ex-ante, and are subject to "run", in the form of roll-over risk. The

[16] This assumption is needed in order to avoid that they accumulate enough wealth, thereby making the intermediary unnecessary.

[17] Individual subscripts are omitted for simplicity: the linearity of the problem allows easy aggregation.

[18] In our simple bank balance sheet the deposit share is the complement to unity of the capital share, $d_t = 1 - \frac{BK_t}{L_t}$. Hence we have a monotonic positive relation between d_t and the bank's leverage, $\frac{L_t}{BK_t}$

manager's task is to find the capital structure that maximizes the combined expected (with respect to the idiosyncratic shock observed ex-post by the bank manager) return of depositors and capitalists, in exchange for a fee. Individual depositors are served sequentially and fully as they come to the bank for withdrawal; bank capitalists are rewarded pro-quota after all depositors are served. This payoff mechanism exposes the bank to runs, that occur when the uncertain return from the project is insufficient to reimburse all depositors. As soon as depositors realize that the payoff is insufficient, they run the bank and force the liquidation of the project; in this case the bank capital holders get zero while depositors get the market value of the liquidated loan. [19]

The lending 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. Such return can be obtained inverting the expression of external finance premium 9, yielding an equation where R_t^A depends positively on $\frac{NW_{t+1}}{Q_t K_{t+1}}$, for given R_t. Moreover, we assume that the return on assets, R_t^A, for the funding department is subject to an idiosyncratic shock x_t with a uniform distribution defined in the space $\{-h; h\}$ [20]. We can think of x_t as a liquidity shock, due for example to a dry up in the interbank market. We assume the bank is a relationship lender: by financing the project, it acquires a specialized non-sellable knowledge of its characteristics that determines an advantage in extracting value from it before the project is concluded, relative to other agents. For this reason the bank is able to repossess the entire return $R_t^A + x$, whereas if outside investors try to liquidate the project without the assistance of the bank manager, they are able to obtain only a fraction λ of the return. This gives the bank a bargaining power, that allows to extract a rent, proportional to the remaining part $(1 - \lambda)$. Notice that, since bank capitalists bear the risk of run, the bank manager rewards

[19] The 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 [25] in this context deposit insurance is inefficient as it distorts banks' incentives.

[20] In Angeloni and Faia [9] 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.

them in the no run states by assigning them part of the rents, $(1-\lambda)$.

The timing is as follows. At time t, the bank manager 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.

Even if the full value is extracted from the project, without loss of relationship knowledge, a bank run entails a specific cost $1 > c \geq 0$; when a run occurs, the value of the project loses a constant fraction c, that can be interpreted as arising from early liquidation.

Consider the payoffs to each of our players, namely the depositor, the bank capitalist and the bank manager. Three possible cases arise.

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 bank manager[21]. Therefore, depositors get

$$\frac{(1+\lambda)(1-c)(R_t^A + x_t)}{2} \tag{13}$$

and the bank manager gets:

$$\frac{(1-\lambda)(1-c)(R_t^A + x_t)}{2} \tag{14}$$

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 manager, but not otherwise; i.e $\lambda(R_t^A + x_t) < R_t d_t \leq (R_t^A + x_t)$. In equilibrium the run does not occur, so depositors are

[21] In Angeloni and Faia [9] 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.

paid in full, $R_t d_t$, and the remainder is split in half between the bank manager 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 value is thus a lower bound for them. The bank manager can extract $(R_t^A + x_t) - R_t d_t$: once again the surplus arising by the bank intervention is split in half with the bank capitalists. Hence the bank manager gets:

$$\frac{\left\{\left[(R_t^A + x_t) - R_t d_t\right] - \left[\lambda(R_t^A + x_t) - R_t d_t\right]\right\}}{2} = \frac{(1-\lambda)(R_t^A + x_t)}{2} \tag{15}$$

an amount lower than the one the capitalist gets. Total payment to outsiders is:

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

The manager chooses d_t to maximize the expected payoff to outside investors; summing up the total expected payments to them in the three cases delivers the following expression:

$$\frac{1}{2h}\int_{-h}^{R_t d_t - R_t^A} \frac{(1+\lambda)(1-c)(R_t^A + x_t)}{2} dx_t + \frac{1}{2h}\int_{R_t d_t - R_t^A}^{\frac{R_t d_t}{\lambda} - R_t^A} \frac{(R_t^A + x_t) + R_t d_t}{2} dx_t + \tag{16}$$
$$+\frac{1}{2h}\int_{\frac{R_t d_t}{\lambda} - R_t^A}^{h} \frac{(1+\lambda)(R_t^A + x_t)}{2} dx_t$$

It can be shown (see [9] for details) that the value of d_t that maximizes equation 16 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

$$\frac{1}{2h}\int\limits_{-h}^{R_t d_t - R_t^A}\frac{(1+\lambda)(1-c)(R_t^A+x_t)}{2}dx_t+\frac{1}{2h}\int\limits_{R_t d_t - R_t^A}^{h}\frac{(R_t^A+x_t)+R_t d_t}{2}dx_t \tag{17}$$

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

$$d_t = z\frac{R_t^A+h}{R_t} \tag{18}$$

Where $z = \frac{1}{2-\lambda+c(1+\lambda)}$. In the following we will refer to $\frac{R_t^A+h}{R_t}$ as the "bank lending premium". Note that the equilibrium deposit ratio, d_t, is inversely proportional to R_t; this is straightforward because d_t and R_t appear only in multiplicative form in the outsiders' payoff function 17. Moreover, d_t, is directly proportional to $R_t^A + h$, the upper limit of the distribution of payoffs. The intuition can be grasped by inspecting equation 17. At the margin, an increase in the deposit ratio affects the payoff function through two channels. First, by increasing the range of realizations of x where a run occurs (raising the upper limit of the first integral) and decreasing the range where a run does not occur (raising the lower limit of the second integral). This effect does not depend on either R_t^A or h. The second channel is an increase of the payoff to outsiders for each x_t in the interval where a run does not occur, i.e. the interval of the second integral of 17. This effect is proportional to $R_t^A + h - R_t d_t$, the size of this interval. From this we can see that the optimal d_t must be homogeneous of degree one in $R_t^A + h$. [22] Note also that the parameter z is positively related to λ and negatively related to c. Intuitively, an increase of c (a higher cost of run)

[22] More formally, a marginal increase in the deposit ratio increases the range of x_t where a run occurs, by raising the upper limit of the first integral; this effect increases the overall payoff to outsiders by $\frac{1}{2h}\left(\frac{(1+\lambda)(1-c)}{2}R_t d_t\right)R_t$. A marginal increase in the deposit ratio also decreases the range of x_t where a run does not occur, by raising the lower limit of the second integral; the effect of this on the payoff is negative and equal to $-\frac{1}{2h}R_t^2 d_t$. Moreover, it also increases the return to outsiders for each value of x_t where a run does not occurs; this effect is $\frac{1}{2h}\left(\int\limits_{R_t d_t - R_t^A}^{h}\frac{1}{2}dx_t\right)R_t = \frac{1}{2h}\left(\frac{R_t^A+h-R_t d_t}{2}\right)R_t$. Equating to zero the sum of these effects and solving for d_t yields equation 18.

decreases the optimal deposit ratio, as does a decrease of λ (a stronger relationship lender effect), for any given value of the bank lending premium $\frac{R_t^A+h}{R_t}$.

From 18 we derive an expression for total bank capital as:

$$BK_t = (1 - z\frac{R_{A,t} + h}{R_t})L_t \tag{19}$$

Note that 19 suggests that the bank lending premium is positively related to bank leverage $\frac{L_t}{BK_t}$; as leverage increases, the market demands a higher premium to continue supplying funds. We will return on this point later. Finally, a natural measure the intermediary's risk in our model is given by the probability of bank runs, defined as:

$$\phi_t = \frac{1}{2h} \int_{-h}^{R_t d_t - R_t^A} dx_t = \frac{1}{2}\left(1 - \frac{R_t^A - R_t d_t}{h}\right) \tag{20}$$

Bank capital accumulation After remunerating depositors and paying the fee to the manager, a return accrues to the bank capitalist as retained earning. Bank capital accumulates from retained earnings as follows:

$$BK_t = \frac{\theta}{\pi_t}[BK_{t-1} + R_t^{BK}(1-\xi)(Q_{t-1}K_t - NW_t)] \tag{21}$$

where R_t^{BK} is the unitary return to the capitalist and $\pi_t = \frac{P_t}{P_{t-1}}$ is inflation, which will be defined and derived in section 4.3 and which enters here since the accumulation involves bank capital at different dates. 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^{BK} can be derived from equation 17 as follows:

$$R_t^{BK} = \frac{1}{2h} \int_{R_t d_t - R_{A,t}}^{h} \frac{(R_t^A + x_t) - R_t d_t}{2} dx_t = \frac{(R_t^A + h - R_t d_t)^2}{8h} \tag{22}$$

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 is obtained substituting 22 into 21:

$$BK_t = \frac{\theta}{\pi_t}[BK_{t-1} + \frac{(R_t^A + h - R_t d_t)^2}{8h}(1-\xi)(Q_{t-1}K_t - NW_t)] \tag{23}$$

The bank capital structure depends on several counterbalancing factors. To gain intuition one can interpret equation 19 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 23 can be seen as a "supply" of bank capital in the following period.

4.3 Producers

Given that our focus is on the analysis of the monetary transmission mechanism, we allow for non neutral effects of monetary policy; to that aim we introduce sticky prices, 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 the parameter ϑ measures the degree of nominal price rigidity. The higher ϑ the more sluggish is the adjustment of nominal prices. 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: $Y_t(i) = A_t F(N_t(i), K_t(i))$.Each monopolistic firm chooses a sequence $\{K_t(i), N_t(i), P_t(i)\}$, taking nominal wage rates W_t and the rental rate of capital Z_t, as given, in order to maximize expected discounted nominal profits:

$$E_0\{\sum_{t=0}^{\infty}\Lambda_{0,t}[P_t(i)Y_t(i) - (W_t N_t(i) + Z_t K_t(i)) - \frac{\vartheta}{2}\left[\frac{P_t(i)}{P_{t-1}(i)} - \pi\right]^2 P_t]\} \tag{24}$$

subject to the following aggregate demand constraint $A_t F_t(\bullet) \leq Y_t(i) = (\frac{P_t(i)}{P_t})^{-\varepsilon} Y_t$, where $\Lambda_{0,t} = \frac{U_{c,t+1}}{U_{c,t}}$ 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. After dividing the profit function by the aggregate price P_t and taking first order conditions, we obtain:

$$\frac{W_t}{P_t} = mc_t A_t F_{n,t} \tag{25}$$

$$\frac{Z_t}{P_t} = mc_t A_t F_{k,t} \tag{26}$$

$$\begin{aligned} 0 \quad = \quad & Y_t \tilde{p}_t^{-\varepsilon}((1-\varepsilon) + \varepsilon mc_t) - \vartheta \left[\pi_t \frac{\tilde{p}_t}{\tilde{p}_{t-1}} - 1 \right] \frac{\pi_t}{\tilde{p}_{t-1}} + \\ & + \vartheta E_t \{ \left[\pi_{t+1} \frac{\tilde{p}_{t+1}}{\tilde{p}_t} - 1 \right] \pi_{t+1} \frac{\tilde{p}_{t+1}}{\tilde{p}_t^2} \} \end{aligned} \tag{27}$$

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 $\tilde{p}_t = 1$. After substituting the stochastic discount factor, and the condition for a symmetric equilibrium, equation 27 takes the following form:

$$\begin{aligned} U_{c,t}(\pi_t - 1)\pi_t \quad = \quad & \beta E_t \{ U_{c,t+1}(\pi_{t+1} - 1)\pi_{t+1} \} + \\ & + U_{c,t} A_t F_t(\bullet) \frac{\varepsilon}{\vartheta}(mc_t - \frac{\varepsilon - 1}{\varepsilon}) \end{aligned} \tag{28}$$

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 obtain a time-varying price of capital. A competitive sector of capital producers combines investment, expressed in the same composite index 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 constant-returns-to-scale production function is $\phi(\frac{I_t}{K_t})K_{t,}$ so that capital accumulation obeys:

$$K_{t+1} = (1-\delta)K_t + \phi(\frac{I_t}{K_t})K_t \tag{29}$$

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 optimal price of assets: $Q_t\phi'(\frac{I_t}{K_t}) = P_t$.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):

$$Y_t^k \equiv Z_t + Q_t((1-\delta) - \phi\prime(\frac{I_t}{K_t})\frac{I_t}{K_t} + \phi(\frac{I_t}{K_t})) \tag{30}$$

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:

$$\frac{R_{t+1}^K}{\pi_{t+1}} \equiv \frac{Y_{t+1}^k}{Q_t} = \frac{mc_{t+1}A_{t+1}F_{k,t+1} + Q_{t+1}((1-\delta) - \phi\prime(\frac{I_{t+1}}{K_{t+1}})\frac{I_{t+1}}{K_{t+1}} + \phi(\frac{I_{t+1}}{K_{t+1}}))}{Q_t} \tag{31}$$

Equation 31 establishes that the aggregate return to capital must equate the marginal productivity of capital, $mc_{t+1}A_{t+1}F_{k,t+1}$, plus the capital gains, $\frac{Q_{t+1}}{Q_t}$, obtained by reselling capital at the end of period t. The capital sold at the end of period t is net of depreciation and of the adjustment costs to investment.

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:

$$\ln\left(\frac{1+R_t}{1+R}\right) = (1-\phi_r)\left[\phi_\pi \ln\left(\frac{\pi_t}{\pi}\right) + \phi_y \ln\left(\frac{Y_t}{Y}\right)\right] + \phi_r \ln\left(\frac{1+R_{t-1}}{1+R}\right) \tag{32}$$

All variables at the denominator, without time subscript, are the target or steady state.

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, hence $T_t = G_t + \Delta_t$, where Δ_t is the aggregate expected loss from deposits (see Appendix 1).

Equilibrium in the final goods 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:

$$Y_t - \Omega_t - \Upsilon_t - \Delta_t = C_t + I_t + G_t + \frac{\vartheta}{2}(\pi_t - 1)^2 \tag{33}$$

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 other sources of output costs connected to bank probability of a run. First, the term $\Omega_t = \frac{1}{2h} \int_{-h}^{R_t d_t - R_t^A} c(1-\xi) R_t^A (Q_t K_{t+1} - NW_{t+1}) dx_t$, 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 the banks in case entrepreneurs fail to repay the loan. Both of them rise when the volatility of the corresponding idiosyncratic components increases.

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 on capital takes the following form: $((\frac{\chi}{2})(\frac{I_t}{K_t} - \delta)^2 K_t)$ and the parameter χ 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 rely on the comparison between the slope of the log-linear Phillips curve in our model, $\frac{\varepsilon-1}{\vartheta}$, with that arising under a Calvo-Yun set up, which is given by $\frac{(1-\hat{\vartheta})(1-\beta\hat{\vartheta})}{\hat{\vartheta}}$, where $\hat{\vartheta}$ is the probability of not resetting the price in any given period. Given the values for the demand elasticity $\varepsilon = 6$, a value of $\hat{\vartheta} = 0.75$, which is compatible with most empirical evidence, the comparison delivers a value for the price stickiness parameter in our model of $\vartheta = \frac{Y\hat{\vartheta}(\varepsilon-1)}{(1-\hat{\vartheta})(1-\beta\hat{\vartheta})} \approx 30$, where Y is steady-state output.

Banks. In the lending department, the parameters for the debt contract, the monitoring cost 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 400 basis points. This delivers a value of the monitoring costs of 3% of asset value and a volatility of corporate risk, σ_ω^2, of 0.15.

In the funding department, to calibrate h we have calculated the average volatility of bank stocks over the last 10 years (GARCH estimates and realized volatilities yield roughly the same result) which is around 0.3, 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.

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 numerical simulations we have chosen a value of 0.5. 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, not the failure rates. Entrepreneurs survival probability, ς, is set according to most parametrization in the financial accelerator literature, namely at a value of 0.975.

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. The first, a productivity shock, is simulated in order to describe the transmission mechanism at work in our model. The monetary policy shock is simulated to analyze the risk taking channel. Total factor productivity is assumed to evolve as $A_t = A_{t-1}^{\rho_\alpha} \exp(\varepsilon_t^\alpha)$.

where the steady-state value A is normalized to unity 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 0.3), as argued by Rudebusch [42]. 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.

5 Model analysis and results

To gain intuition and make the analysis of this rather complex model more manageable, we proceed in two steps: first, in the next subsection, we discuss the working of both sides of the bank (liabilities and assets), intuitively explaining how their interaction influences the transmission of monetary policy. Then, in the next subsection we examine two impulse responses, respectively to a monetary policy shock and a productivity shock (with endogenous response of monetary policy).

5.1 The unfolding of risk: interaction of balance sheet and risk taking channels

The intermediation sector of our model can be laid down in four equations: two premia and two asset accumulations. From now on for simplicity, and in order to isolate the banking effects, we will assume that $\xi = 0$. On the side of the funding department, the bank lending premium (BLP) reads as follows:

$$\frac{R_t^A + h}{R_t} = z^{-1}\left(\frac{D_t}{Q_{t-1}K_t - NW_t}\right) = z^{-1}\left(\frac{D_t}{D_t + \ BK_t}\right) \tag{34}$$

The accumulation of bank capital reads as follows:

$$BK_t = \theta[BK_{t-1} + \frac{(R_t^A + h - R_t d_t)^2}{8h}(Q_{t-1}K_t - NW_t)] \tag{35}$$

On side of the lending department, the external finance premium (EFP) is:

$$\frac{R_{t+1}^K}{R_t^A} = \psi\left(\frac{NW_{t+1}}{Q_t K_{t+1}}\right) = \rho(\varpi_{t+1}) \tag{36}$$

(with $\psi' < 0$). The entrepreneurs' net worth accumulation is given by:

$$NW_{t+1} = \varsigma R_t^K Q_{t-1}K_t - \varsigma \left\{R_{A,t} + m_t\right\}(Q_{t-1}K_t - NW_t) \tag{37}$$

Let's now analyze the functioning of the two departments in isolation and then combined. We will focus on the resulting dynamic of bank riskiness and on of real variables (primarily output and investment) in response to a monetary restriction occurring at time $t-1$. We will then consider the effects of other shocks.

- *Funding department.* Consider first the functioning of the funding department in isolation. This essentially means setting the EFP constant and equal to one. The interest rate increase triggers a fall in asset prices and investment. Two effects operate in the funding side. First, the fall in project values induces the bank to reduce the demand for outside funding $(D_t + BK_t)$. This captures a *banks' balance sheet* channel: as bank lending values decrease, liabilities do so as well. Second, other things equal, an increase in the policy rate makes short term funding, D_t, more expensive compared to bank capital, hence the bank reduces short term liabilities more than proportionally relative to bank capital. This reduces bank leverage and risk, capturing the essence of the *risk taking channel*. Consider now the effect on the bank lending premium. The left-hand side of equation 34 falls since, as just mentioned, the right-hand side falls; hence BLP falls. The movements of output, relatively to a model without risk taking channel, are mainly driven by the expected resource cost of run and the expected loss on deposits, Ω_t and Δ_t: as risk falls these variables do as well, therefore *dampening* the initial fall in output.

- *Lending department.* The effects of the monetary policy shock follow the conventional financial accelerator mechanism. The fall in the asset price brings about a fall in entrepreneurs' balance sheet, which drives an increase in the EFP. The ensuing increase in the cost of loan services triggers a further fall in investment, asset price and entrepreneurs' balance sheet. This mechanism results in an *accelerated* fall in investment and output.

- *Combined effects.* As outlined above, in presence of a risk taking channel, the fall in asset prices produces a fall in D_t more than proportional to BK_t, hence the bank capital structure becomes less risky. The increase in the interest rate leads to a decline in net worth that induces a decline in the BLP via equation 34, hence the banks' returns on asset, R_t^A, rises more than in the AF model. The funding department reacts by decreasing leverage and risk by more; hence in the combined model the fall in bank risk is also *amplified* relatively to the model featuring solely the risk taking channel. Recall that fluctuations in bank risk affect the resource costs due to the risk of run and to the risk premium on deposits, respectively Ω_t and Δ_t: in the combined model the larger fall in bank risk produces a larger fall in the resource costs, therefore *dampening* the initial output contraction, relatively to both the model with the risk taking channel alone and that with the financial accelerator alone.

All in all in the combined model we should expect larger fluctuations in the dynamic of bank riskiness and more muted fluctuation in output and its components (investment and consumption).

Consider now an increase in productivity, A_t. There are two contrasting effects. On the one hand, a productivity increase, by lowering inflation on impact, should increase bank risk via the risk-taking channel. On the other hand, however, it also brings about an increase in the return on capital R^K_{t+1}, as seen from the equation describing the return to capital investment 31. The increase in R^K_{t+1} leads to an increase in R^A_t, that is also reinforced by the fall, in the medium run, of the EFP, as can be seen by rearranging equation 36 to obtain $R^A_t = \frac{R^K_{t+1}}{\psi(\frac{NW_{t+1}}{Q_t K_{t+1}})}$; as firms' balance sheet conditions improve, the EFP falls, thereby amplifying the increase in R^A_t. For the funding department, this implies less risk, as per equation $R^A_t + x_t < R_t d_t$, the more so the larger the increase in R^A_t. As seen earlier, the fluctuations in bank riskiness are reflected in the fluctuations of the resource costs, hence in output.

To complete our assessment of how firms' and banks' balance sheet risks interconnect, let's now consider an exogenous increase in the riskiness of investment projects, σ^2_ω, or, more generally, in the probability that entrepreneurs fail to repay the loan (a mean preserving shift in the density of the distribution to the tails). Such an increase triggers an increase in the EFP, which, via equation 36, reduces R^A_t. This increases the probability of run. Once again, the increase in intermediary's risk produces an increase in resource costs and depresses output. This is another illustration of the self-reinforcing nature of risk in our model: an increase in risk on the asset side, due for instance to shift toward fat tails distributions, also increases the likelihood of runs in the liability side.

5.2 Model results

We now illustrate the mechanisms just described by showing impulse responses to two shocks: a moderately persistent monetary contraction and a very persistent increase in productivity. We compare the results of three models. The first (the one we labelled AF) includes only the funding unit of the bank, as in AF, and hence features solely the risk taking channel on the liability side. The second (labelled BGG) is the classical financial accelerator, which includes only the lending unit of the bank[23]. The third is a "combined model" (labelled AFBGG) that includes both sides of the bank and the full interactions described above. Note that, in the charts, some variables are specific to the models with endogenous bank liability structure, AF and the AFBGG (for example, the deposit ratio and bank riskiness), while other variables are specific to the models with financial accelerator, BGG and AFBGG (for example, the external finance premium).

Figure 2 shows the impulse response to a monetary restriction: in all models, output, investment and asset prices decline. The decline in output is sharper in the BGG model due to the financial accelerator channel. Both the AF and the AFBGG feature a risk taking channel: the funding department reduces the deposit ratio and bank risk decreases. As explained in the previous paragraph the fall in asset prices triggers a fall of required bank funding: this induces a fall in D_t, which, due to the risk taking channel, is more than proportional to the fall in BK_t, and triggers a fall in bank riskiness. Comparing the combined model AFBGG with AF, one has to consider that the decline in net worth, following the increase in the interest rate, induces a decline in the BLP via equation 34, hence the banks' returns on asset, R_t^A, rises in AFBGG less than in AF. The funding department reacts to this by decreasing leverage by more (panel 4:1 in the figure). In equilibrium this makes bank risk also decline more (panel 4:2). The larger decline in bank risk in the combined model

[23]The BGG model is calibrated so as to generate steady state levels of the EFP and of the firms' default probability which are equivalent to the ones featured in the AF_BGG. This implies that the cost of monitoring and the σ_ω^2 in the BGG model have to be set respectively to the 5% of the asset value and to 0.3.

produces a decline (in relative terms) in the resource costs, which dampens the fall in output relatively to both the AF and the BGG model[24].

A further consideration: the fall in the banks' returns on asset R_t^A in AFBGG explains also, via equation 37, a higher level of net worth relative to BGG (in both models net worth declines, but less so in AFBGG relative to BGG). This is sufficient to generate, in AGBGG, a decline in the EFP, that contrasts with the increase observed in BGG.

Figure 3 shows impulse responses to a productivity increase. Again, BGG features the strongest initial effect on output. This matches the fact that the EFP and the probability that entrepreneurs will not repay decline in BGG: healthier firms' balance sheets trigger further increases in investment and asset prices, which then lead to the well known accelerated dynamics. In the AF model the deposit ratio and bank riskiness increase, due to the fall in the interest rate: this triggers an increase in the resource costs associated with the bank run; as a result the increase in output is dampened relatively to the BGG model. The combined model features a different dynamic in the short run relative to the medium to long run: this is mainly due to the nature of the shock, which is now very persistent. In the short run bank riskiness increases, as the risk taking channel prevails: as in the AF model this comes along with a sharp fall in R_t^A, as from equation 34, which brings about an increase of the EFP on impact, as from equation 36. The short run increase in bank riskiness produces an increase on impact of the resource costs: this depresses the increase in output relatively to both the AF and the BGG model. Things are different in the medium to long run: as the nominal interest rate declines strongly (from the 2nd to the 5th quarter) firms' balance sheet improves, the EFP declines, moving below the baseline, and banks' returns on assets increase as from $R_t^A = \frac{R_{t+1}^K}{\psi(\frac{NW_{t+1}}{Q_t K_{t+1}})}$. This reduces the probability of a run which declines sharply

[24]English et al. [27] have recently found an inverse effect of short term rate surprises on bank stocks. In our case, a positive interest rate shock has two effects. On the one hand, it increases the payoff accruing to the capitalist; this can be seen by noting, inspecting equations 20 and 22, that the latter is positively related to bank risk, which is known to decrease. On the other hand, however, a monetary restriction depresses the firms' net worth, hence reducing R_t^A other things equal. Casual obervation of the period prior to the crisis suggests that a persistent monetary expansion was accompanied by high bank profitability, high output and (as recognised ex-post) high bank riskiness.

in the intermediate quarters. As usual, the movements in bank riskiness are mirrored in the fluctuations of the resource costs and in output: as bank riskiness declines output recovers, first relatively to the AF model and then also relatively to the BGG model.

Note that, while the link between EFP and the cycle in the financial accelerator model is unambiguously negative, the relation between BLP and the cycle in both AF and AFBGG depends on the origin of the disturbance.

6 Conclusions

As a consequence of the financial crisis, a broad reflection is underway on the working of the transmission mechanism of monetary policy in presence of financial risks. There is a growing perception that existing macro models that do not incorporate financial sectors and financial risks cannot provide a convincing representation of the effects of monetary policy, particularly when the banking and financial sectors are distressed.

Most macro-models inherited from earlier years incorporate financial factors through a financial accelerator mechanism. We augment this standard model by adding a micro-founded banking system, drawn, in its broad lines, from Angeloni and Faia [9]. The model embodies an endogenous determination of bank risks, measured by the probability of the bank incurring into a run on its deposits. In this model, monetary policy affects bank risks, and bank risks in turn contribute to shaping the transmission of monetary policy ("risk taking channel" of monetary transmission).

The model we present here is clearly not an endpoint in a research line; we regard it as an interesting benchmark for further progress in understanding the interlinkages between the financial sector and the macroeconomy. Our summary conclusions at this stage are the following. There is evidence that an expansionary monetary policy increases, with lags, the propensity of banks to assume risk (a "risk taking channel" of monetary transmission). This evidence upholds the case for incorporating this mechanism into macro-models. Our model combines banks with an endogenous capital structure on the liability side (generating a risk of bank run) with a financial accelerator on the asset side (that embodies a risk of borrower default). We find that the model combining the two sources of risk contains a number of novel features concerning monetary transmission. Risks on the asset side and on the liability side of banks tend to move together and reinforce each other. Importantly, the "risk taking channel" tends to dampen the impact of monetary policy on output; that turns out to be substantially weaker than in a pure financial accelerator model. This attenuation mechanism operates when the two risks are combined; as a consequence, the transmission in our model can be weaker also relative to a model in which only funding risks are modelled and there is no financial accelerator.

References

[1] Adrian, Tobias and Hyun Song Shin (2008). "Financial Intermediaries, Financial Stability and Monetary Policy." presented at the Kansas City Fed Symposium at Jackson Hole, August 21-23.

[2] Acharya, Viral and Hassan, Naqvi, (2010). "The Seeds of a Crisis: A Theory of Bank Liquidity and Risk Taking over the Business Cycle." NYU.

[3] Agur, Itai and Demertzis, Maria, (2010). "Monetary Policy and Excessive Bank Risk Taking." Discussion Paper 2010-30S, Tilburg University, Center for Economic Research.

[4] Alessi, Lucia and Carsten Detken (2008). "Real time early warning indicators for costly asset price boom/bust cycles: a role for global liquidity." ECB Working papers n. 1039.

[5] Allen, Franklin and Douglas Gale, (1998). "Optimal Financial Crises". *Journal of Finance,* 53, 1245-1283.

[6] Allen, Franklin and Douglas Gale, (2000). "Bubbles and Crises." *Economic Journal*, 110, 236-255.

[7] Allen, Franklin and Douglas Gale, 2007, *Understanding Financial Crises*, Oxford University Press.

[8] Altunbas Y., L. Gambacorta and D. Marques-Ibanez, (2009). "An Empirical Assessment of the Risk-Taking Channel." BIS, mimeo. dowloadable at: http://www.ecb.int/events/pdf/conferences/ecb_bis/paper_altunbas_gambacorta_marques.pdf

[9] Angeloni, Ignazio and Ester Faia (2011). "Capital Regulation and Monetary Policy with Fragile Banks." mimeo.

[10] Angeloni, Ignazio, Anil Kashyap and Benoît Mojon, (2003). *Monetary Policy Transmission in the Euro Area*, Cambridge University Press.

[11] Bernanke, Ben and Mark Gertler, (1999). "Monetary policy and asset price volatility." Proceedings, Federal Reserve Bank of Kansas City, pages 77-12.

[12] Bernanke, B., M. Gertler and S. Gilchrist, (1999). "The Financial Accelerator in a Quantitative Business Cycle Framework." in J.B. Taylor, and M. Woodford, eds., *Handbook of Macroeconomics*, Amsterdam: North-Holland.

[13] Bekaert, G., M. Hoerova and M. Lo Duca, (2009). "Risk, uncertainty and monetary policy." mimeo, ECB, Frankfurt.

[14] Bekaert, G., M. Hoerova and Scheicher, (2009). "Uncertainty and Risk Attitude: Evidence from Equity Markets." ECB Working Paper No. 1037.

[15] Bils M. and P. Klenow (2004). "Some Evidence on the Importance of Sticky Prices." *Journal of Political Economy*, October.

[16] Bloom, Nicholas, (2009). "The Impact of Uncertainty Shocks." *Econometrica*, May.

[17] Bloom, Nicholas, Max Floteotto and Nir Jiaimovich, (2010). "Really Uncertain Business Cycles." Mimeo.

[18] Borio, Claudio and H. Zhu (2008). "Capital regulation, risk-taking and monetary policy: a missing link in the transmission mechanism?" BIS Working Papers No. 268.

[19] Borio, Claudio and Philip Lowe (2002). "Asset prices, financial and monetary stability: exploring the nexus", BIS Working Papers No 114.b

[20] Brunnermeier, M., A, Crockett, C. Goodhart, M. Hellwig, A. Persaud and H. Shin, (2009). "The Fundamental Principles of Financial Regulation." Geneva Report on the World Economy 11, CEPR and ICMB.

[21] Cecchetti, S.G., H. Genberg, J. Lipsky and S. Whadwani, (2000). "Asset Prices and Central Bank Policy." Geneva Report on the World Economy 2, CEPR and ICMB.

[22] Dell'Ariccia, Giovanni, Laeven, Luc and Marquez, Robert (2010). "Monetary Policy, Leverage, and Bank Risk-Taking." IMF Working Papers 10/276, International Monetary Fund.

[23] De Nicolo', Gianni, (2006). "Bank Risk-Taking and Competition Revisited: New Theory and New Evidence" IMF Working Paper No. 06/297.

[24] Diamond, Douglas W. and Rajan, Raghuram G. (2000). "A Theory of Bank Capital." *Journal of Finance*, vol. LV. No. 6.

[25] Diamond, Douglas W. and Raghuram G. Rajan, (2001). "Liquidity Risk, Liquidity Creation and Financial Fragility: A Theory of Banking." *Journal of Political Economy.*

[26] Eichengreen, Barry, Mohamed el-Erian, Arminio Fraga, Takatoshi Ito, Jean Pisani-Ferry, Eswar Prasad, Rachuram Rajan, Maria Ramos, Carmen Reinhart, Helene Rey, Dani Ridrik, Ken Rogoff, Hyun Song Shin, Andres Velasco, Beatrice Weder di Mauro, Yongding Yu (2011) *Rethinging Central Banking*, Brookings Institution

[27] English, William B., Skander Van den Heuvel and Egon Zakrajsek, (2011). "Interest Rate Risk and Bank Equity Valuation", mimeo

[28] Faia, Ester, and Monacelli, Tommaso, (2007). "Optimal interest rate rules, asset prices, and credit frictions." *Journal of Economic Dynamics and Control*.

[29] Goodhart, Charles and Boris Hofmann (2008). "House Prices, Money, Credit and the Macroeconomy." ECB Working paper Series n. 802.

[30] Goodhart, Charles and Dirk Schoenmaker (1995). "Should the Functions of Monetary Policy and Banking Supervision be Separated?" *Oxford Economic Papers*, 47, 539–560.

[31] Harrison, J. Michael and Kreps, David M., (1979). "Martingales and arbitrage in multiperiod securities markets." *Journal of Economic Theory*, vol. 20(3), pages 381-408, June.

[32] Jiménez, J., S. Ongena, J.-L. Peydró-Alcalde and J. Taurina (2007). "Hazardous Times for Monetary Policy: What do Twenty-Three Million Bank Loans Say About the Effects of Monetary Policy on Credit Risk?" CEPR Discussion Paper 6514.

[33] Kashyap, A. and F. Mishkin (2009). "The Fed is Already Transparent." the Wall Street Journal, 10 November.

[34] Laeven, Luc, Dell'Ariccia, Giovanni and Robert Marquez, (2010). "Monetary Policy, Leverage, and Bank Risk-Taking." IMF Working Papers 10/276.

[35] Maddaloni A., and J.L. Peydró Alcalde, (2009). "Bank risk-taking, Securitization and Monetary Policy; Evidence from the bank Lending Survey", ECB, mimeo. Downloadable at: http://reserved03.timeandmind.net/carefin.unibocconi.it/download/21_settembre_Intesa_Sanpaolo/peydro-maddaloni.pdf

[36] Mishkin, Rick and John Taylor, (2005). "The monetary transmission mechanism: an empirical framework", Journal of Economic Perspectives, 9, 4

[37] Morris, S. and H.S. Shin, (2008). "Financial Regulation in a System Context." Brookings Papers of Economic Activity.

[38] Rajan, Raghuram (2005). "Has Financial Development Made the World Riskier?" NBER Working Paper 11728.

[39] Sbordone A. (2002). "Prices and Unit Labor Costs: A New Test of Price Stickiness." *Journal of Monetary Economics* Vol. 49 (2).

[40] Reinhardt, Carmen and Ken Rogoff, (2009). "Is the 2007 U.S. sub-prime financial crisis so different? An international comparison." NBER Working Paper 13761.

[41] Rotemberg, Julio J, (1982). "Monopolistic Price Adjustment and Aggregate Output." *Review of Economic Studies*, vol. 49(4), pages 517-31.

[42] Rudebusch, Glenn D., (2002). "Term structure evidence on interest rate smoothing and monetary policy inertia." *Journal of Monetary Economics*, vol. 49(6), pages 1161-1187, September.

[43] Taylor, J.B. (2009), "The Financial Crisis and the Policy Responses: An Empirical Analysis of What Went Wrong." NBER Working Paper Series No. 14631.

7 Appendix 1. Expected return on risky deposits

The expected return on deposits, taking into account the positive probability of bank run, is below the riskless return R_t. Consider the return on deposits per unit of funds intermediated by the bank 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 $\frac{(1+\lambda)(1-c)(R_t^A+x_t)}{2}$. This holds in the interval of x_t comprised between $[-h;(R_t d_t - R_t^A)]$. The expected value of this payoff is $\frac{1}{2h}\int\limits_{-h}^{R_t d_t - R_t^A} \frac{(1+\lambda)(1-c)(R_t^A+x)}{2} dx_t$. This can be written, solving the integral and using equation 20, as

$$\begin{aligned}
\frac{(1+\lambda)(1-c)}{2}\int\limits_{-h}^{R_t d_t - R_t^A}\frac{(R_t^A+x_t)}{2h}dx_t &= \frac{(1+\lambda)(1-c)}{2}\left[\phi_t R_t^A + \frac{1}{2h}\frac{(R_t d_t - R_t^A)^2 - h^2}{2}\right] \\
&= \phi_t \frac{(1+\lambda)(1-c)}{2}\left(R_t^A + \frac{R_t d_t - R_t^A - h}{2}\right) \\
&= \frac{1}{4}\phi_t(1+\lambda)(1-c)(R_t d_t + R_t^A - h)
\end{aligned}$$

In the range of x_t in which the run does not occur, the expected return is equal to the riskless payoff $R_t d_t$ multiplied by the probability of the respective event, $(1-\phi_t)$.

The expected payoff on deposits per unit of intermediated funds is given by:

$$\frac{1}{4}\phi_t(1+\lambda)(1-c)(R_t d_t + R_t^A - h) + (1-\phi_t)R_t d_t$$

The expected loss on deposits, relative to the no-default state, per unit intermediated funds, is obtained subtracting the above expression from $R_t d_t$, the return in the no-default state

$$R_t d_t - \left\{\frac{1}{4}\phi_t(1+\lambda)(1-c)(R_t d_t + R_t^A - h) + (1-\phi_t)R_t d_t\right\} =$$

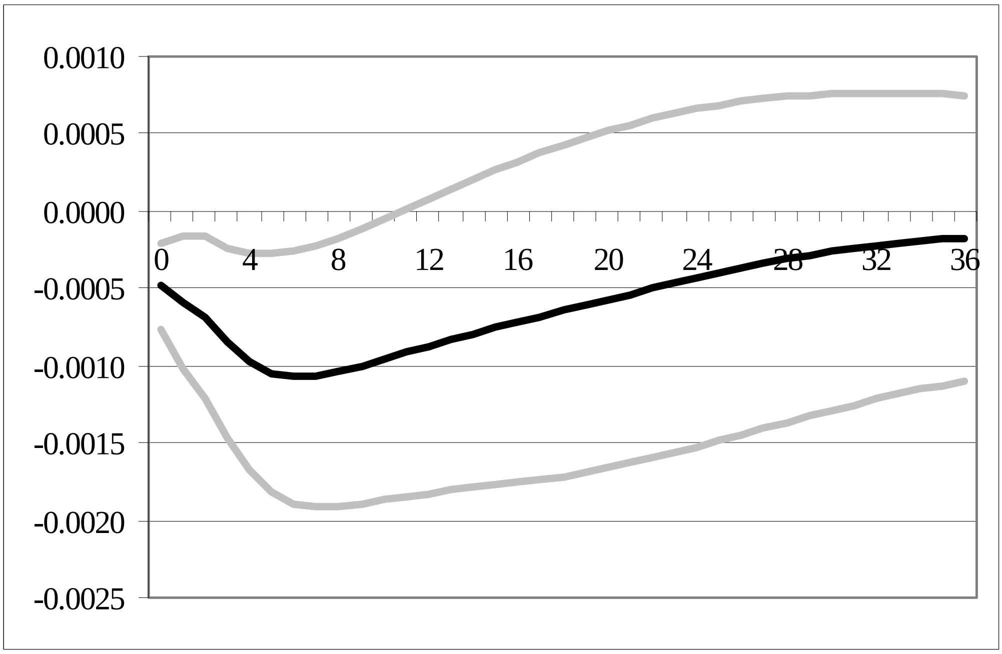
$$= \phi_t \left[R_t d_t - \frac{1}{4}(1+\lambda)(1-c)(R_t d_t + R_t^A - h) \right]$$

The aggregate expected loss on deposits is equal to the above expression multiplied by the total amount of finds intermediated by the bank, $(1-\xi)(Q_t K_{t+1} - NW_t)$

$$\Delta_t = (1-\xi)(Q_t K_{t+1} - NW_t)\phi_t \left[R_t d_t - \frac{1}{4}(1+\lambda)(1-c)(R_t d_t + R_t^A - h) \right]$$

FIGURE 1: VAR IMPULSE RESPONSE OF BANK RISK
TO A CONTRACTIONARY MONETARY POLICY SHOCK

Response of Bank Funding Risk to a Monetary Policy Shock



Response of Bank Overall Risk to a Monetary Policy Shock

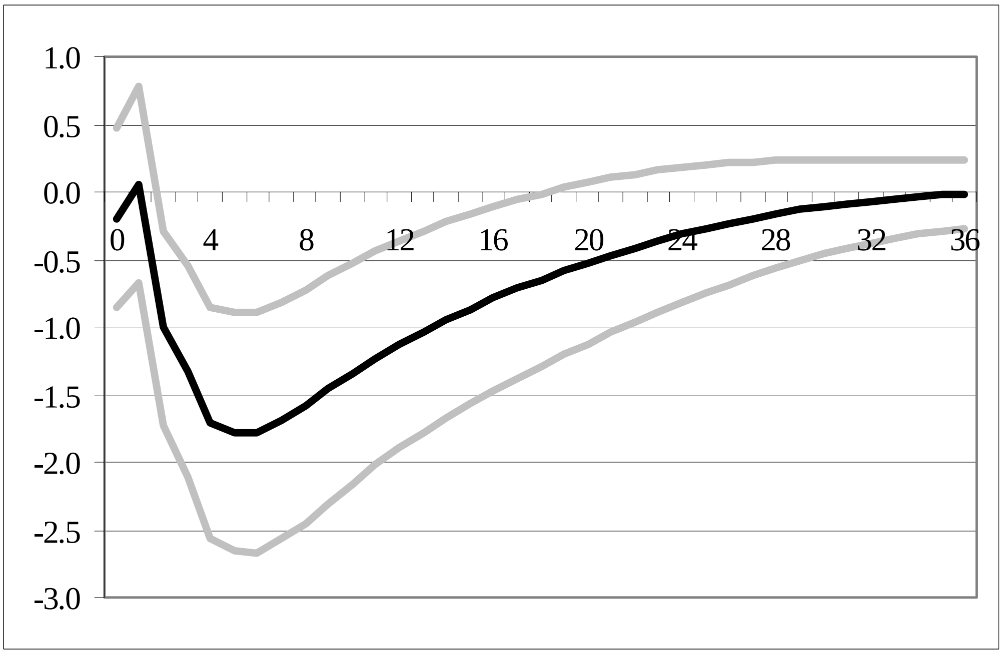


FIGURE 2: MODEL IMPULSE RESPONSES TO A CONTRACTIONARY MONETARY POLICY SHOCK

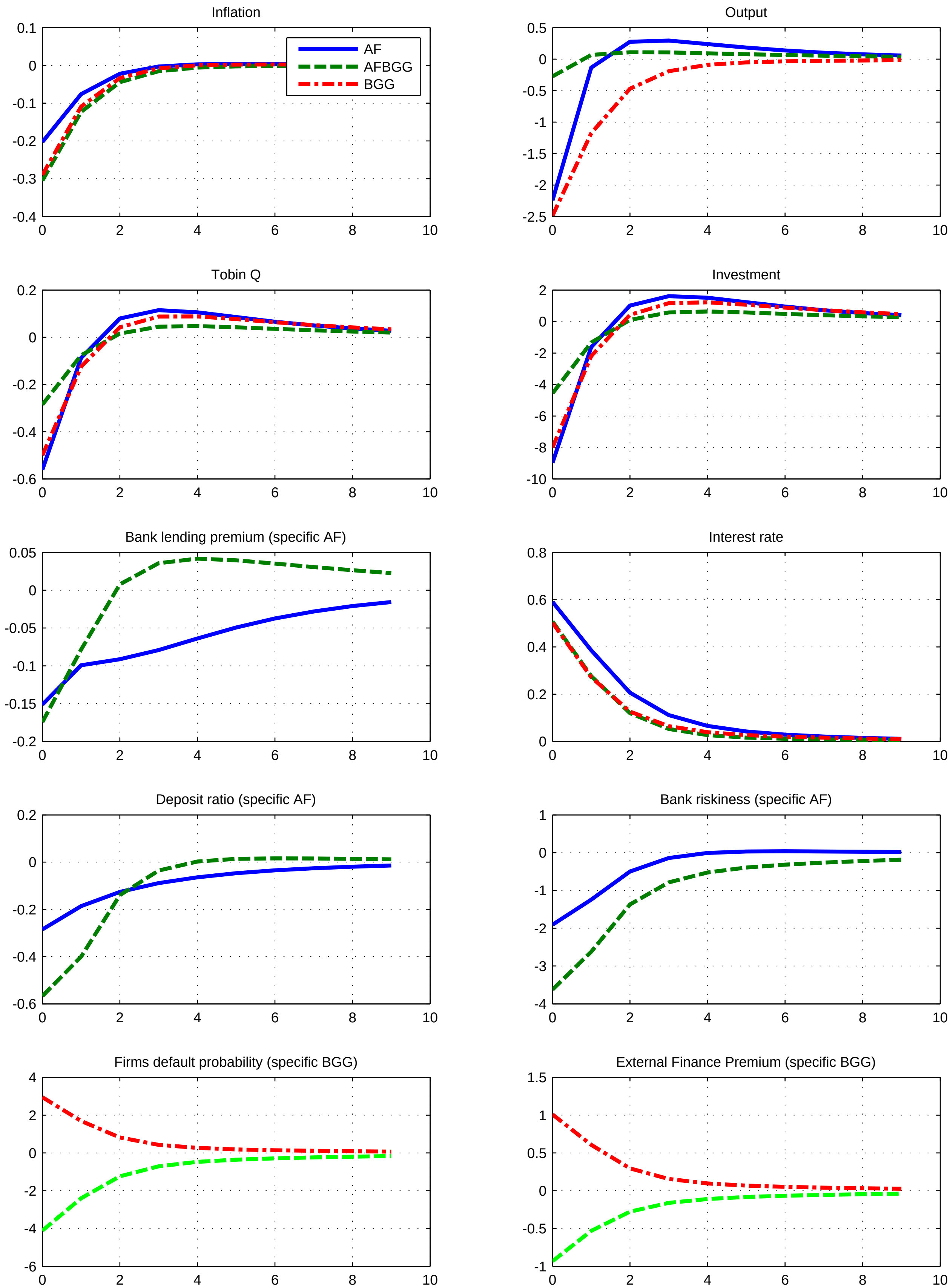
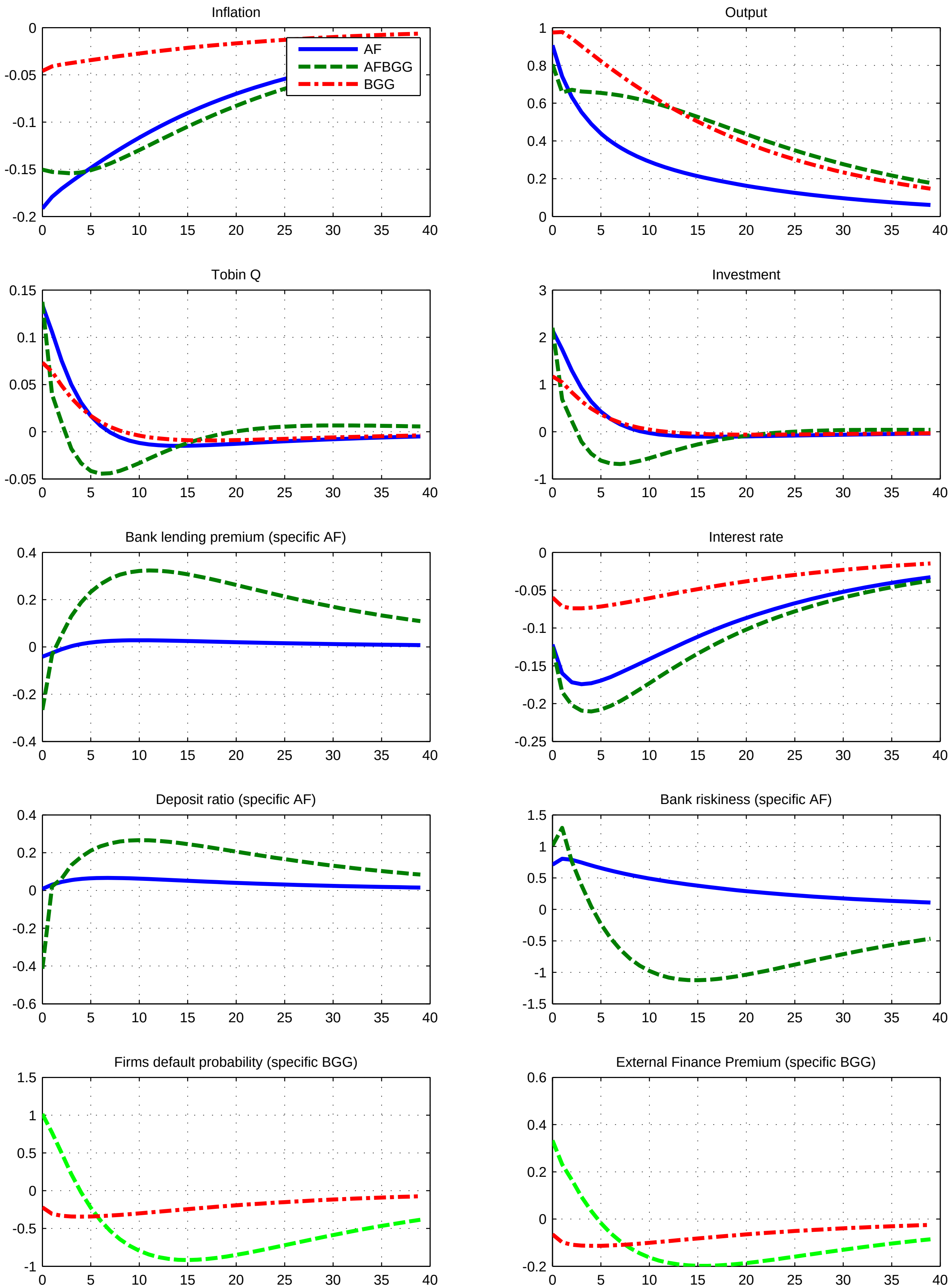


FIGURE 3: MODEL IMPULSE RESPONSES TO AN EXPANSIONARY PRODUCTIVITY SHOCK



DATA APPENDIX

Variable name	Description
Industrial production index	De-trended logarithm of the industrial production index (excluding construction). Source: Authors' calculation and Datastream.
Employment	De-trended logarithm of total employment in non farm industries. Source: Authors' calculation and Datastream.
Commodity price inflation	De-trended logarithm of a commodity price index (Commodity Research Bureau Spot Index) Source: Authors' calculation and Datastream.
Consumer price inflation	De-trended logarithm of Consumer Price Index (All items All urban areas). Source: Authors' calculation and Datastream
Monetary policy rate	De-trended effective Federal Fund rate. Source: Authors' calculation and FED.
Uncertainty shock - Risk	Realised volatility of the S&P500 index. This variable captures the uncertainty shock of Bloom (2009). Source: Authors' calculation and Datastream.
Bank Funding Risk	Ratio market based funding to banks' total assets. Market based funding is the difference between total liabilities (excluding equity capital) and customer deposits. Source: Authors' calculation and FED (Difference between line 42 and line 31 of the table H8 for Commercial Banks in the US).
Bank Asset Risk (only in the model at quarterly frequency)	Percentage of banks tightening credit standards on commercial and industrial loans to large and medium enterprises. Source: FED Survey of Terms of Business Lending.
Bank overall risk	Realised volatility of the Datastream banking index for the US Source: Authors' calculation and Datastream.

Notes: The order of the variables in the table reflects the order of the variables in the VAR, i.e. the shock to the macro variable is exogenous, while the shock on bank risk, the last shock, is a combination of all the other shocks. The model is as close as possible to Bloom (2009). The Estimation period of the baseline model is January 1980 – September 2011. De-trending has been done with the Hodrick-Prescott filter (λ = 14400). Realised volatilities over one month are computed as the average of the daily absolute returns of the S&P500 over the month