Monetary Policy and Risk Taking*

Ignazio Angeloni
European Central Bank and BRUEGEL

Ester Faia
Goethe University Frankfurt and CFS

Marco Lo Duca
European Central Bank

First draft: November 2009. This draft: August 2013

Abstract

We assess the effects of monetary policy on bank risk to verify the existence of a risk-taking channel – monetary expansions inducing banks to assume more risk. We first present VAR evidence confirming that this channel exists and tends to concentrate on the bank funding side. Then, to rationalize this evidence we build a macro model where banks subject to runs endogenously choose their funding structure (deposits vs. capital) and risk level. A monetary expansion increases bank leverage and risk. In turn, higher bank risk in steady state increases asset price volatility and reduces equilibrium output.

Keywords: bank runs, risk taking, monetary policy.

JEL: E4,E5,G01.

*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 participants at various seminars and conferences. Ester Faia acknowledges financial support from the EU grant SSH-CT-2009-225149. The authors are the sole responsible for the content of the paper.

1 Introduction

According to a growing stream of opinion, the 2007 financial crisis originated from mis-incentives in the financial markets leading to excessive leverage and risk-taking by financial institutions. High liquidity and persistently low interest rates, combined with lenient bank supervision, allegedly induced banks to finance an increasing volume of risky assets – largely in the real estate sector – by means of cheap short-term funding. This line of argument calls into question the links between monetary policy and financial risk-taking. Largely neglected prior to the crisis – with some notable exceptions, mentioned below – such links are now increasingly discussed[1], but two elements are missing to provide a foundation to the argument: realistic macroeconomic models that endogenize risk taking behavior and relate it to monetary policy, and time-series evidence documenting this relation.

We move in that direction in two ways. First, we look at time series evidence on the link between monetary policy and risk taking. The empirical literature has been confined to survey and panel data evidence; no aggregate-level time series tests are available. Tests involving aggregate dynamics are important because interest rate changes are likely to influence bank balance sheet risk in different ways at different time lags: in the short run, risk is likely to be positively correlated with interest rates, but in the longer run this relation may be inverted if the risk-taking channel dominates. Our time series evidence supports the notion that monetary policy influences risk-taking in the banking sector after some lags via changes in the funding side. Second, we propose a model with risky banks that rationalizes such channel. Fundamental bank runs in our model arise as a discipline device from uninformed investors holding demand deposits (uninsured short term liabilities) subject to service constraints: when a run materializes, banks liquidate projects and this entails a resource cost. Low policy rates reduce the cost of short term finance to banks and, if protracted, provide an implicit guarantee that indirectly impairs market discipline. When rates are low, banks substitute bank capital with short term funding, raising bank riskiness. In the end this leads to an aggregate resource costs for the economy.

Banks endogenously choose between two sources of funding, demand deposits (uninsured short-term liabilities) and bank capital, to finance risky investment projects. Bank

[1]For a recent review of the debate see Dell'Ariccia et al. [13].

managers have an informational advantage on the projects they finance and act as relationship lenders on behalf of outside financiers. To insure against the possibility that bank managers withhold their skills, depositors threaten a run when news about projects returns become common knowledge[2]. Bank managers are compensated based on a bargaining agreement which maintains their incentives to maximize expected projects' returns. A monetary easing reduces the cost of demand deposits relatively to the cost of bank capital. Higher bank leverage increases bank riskiness, measured by the probability of a bank run occurring. As the probability of bank runs in our model changes with the cycle and other macro and policy variables implies that our model can account for endogenous evolution of risk over the business cycle[3].

A novel aspect of our framework consists in embedding fundamental bank runs into a macro model for policy analysis. Diamond and Dybvig [14] modelled panic based banks runs in a partial equilibrium and static context: they analyzed panic runs triggered by liquidity shocks on depositors. Since then, the banking literature has evolved; on the one hand, empirical evidence[4] has documented a correlation between banks' runs and changes in fundamentals; on the other, the notion of purely panic-based run does not lend itself easily to policy analysis, because of the difficulty of pinning down an endogenous probability of bank runs (there are two rational equilibria, each with equal probability). For this reason the theoretical banking literature moved towards considering fundamental and information-based bank runs, ultimately triggered by bad news on investment returns. We follow this latter notion of bank run, embedding it into a macro model and analyzing its interaction with monetary policy.[5]

We obtain two main results. First, an expansionary monetary policy raises bank leverage and risk. Similar results obtain under a positive productivity shock, due to the fact that monetary policy becomes more expansionary (the real interest rate declines) under the

[2]See Diamond and Rajan [15], [16] and more recently Angeloni and Faia [4]

[3]Assenza and Delli Gatti [6] also model the endogenous evolution of risk but in a model with heterogenous firms.

[4]See among others Kaminsky and Reinhardt [18], Calomiris and Mason [11] for links between bank runs and fundamentals.

[5]See also Diamond and Rajan [15],[16]. In a companion paper, Angeloni and Faia [4], which provides normative analysis within the same model, we also show that our model is successful in matching the main macroeconomic and banking business cycle statistics.

assumption that the central bank target expected inflation. The effects of the monetary expansion on output and inflation are the conventional ones – they both rise – but they are milder than in a corresponding model without banks; a dampening of monetary policy transmission occurs because risk-taking by banks is contractionary, hence it compensates in part the expansionary first-round effect. We also discuss the effects of projects riskiness (hence bank riskiness) on the long run levels and the volatility of output and assets prices. The literature found extensive evidence that an increase in riskiness (as signaled by the arrival of bad news) raises the volatility of output and reduces its long run level[6] as well as raises the volatility of asset prices and reduces its long run level[7]. Our model confirms those links, but highlights a new channel that stems from the endogenous formation of risk: when investment project risk increases, and as investors become aware of such increase, more bank runs occur. This raises the volatility of bank funding and investment and lowers production prospects in the long run.

The paper is organized as follows. In section 2 we briefly review some recent literature on the risk taking channel of monetary policy. In section 3 we present time-series evidence on the transmission of monetary policy on bank risk in the US. In section 4 we present our macro model with bank runs. In section 5 we analyse the model and its quantitative properties, mostly in relation to our time series evidence. Finally, section 6 concludes. Appendices and tables follow.

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[8] in the earlier literature on monetary policy transmission. The classic 1995 survey by Mishkin, Taylor and others in the Journal of Economic Perspectives [20] hardly mentions bank and financial risks at all. In the multi-country empirical study of monetary transmission in the euro area

[6] See Bloom [8].

[7] See for instance Bae, Kim and Nelson [7].

[8] As explained earlier by risk here we mean mainly indicators of endogenous formation of risk, not merely exogenous financial shocks.

conducted by the Eurosystem central banks, dated 2003[9], indicators of bank risk are actually used in the econometric estimates of the “lending channel”, but only to measure how changes in certain structural characteristics of banking sector affect the strength of the transmission, not because monetary policy may itself influence those characteristics. Recently a Mishkian view of endogenous risk formation is proposed in Assenza and Delli Gatti[6] but in a model with heterogenous firms.

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 [1] 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 [2], consists in the fact that aggregate credit developments in the economy are, at least partly, under the control of monetary authorities. Borio and Lowe [10], 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[10].

To help the subsequent analysis, it is useful to distinguish between two different channels through which risk-taking behavior can operate. The first refers to accumulation of excessive risk on the funding side. An expansionary monetary policy may affect the composition of bank liabilities, altering the mix of capital (plus other stable funding sources) 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. The second channel 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 (see for instance Rajan [23]). Risk taking on the funding side may in fact initiate and amplify risk taking on the asset side: as banks can transfer risk to outside financiers, through higher leverage, their

[9] See Angeloni, Kashyap and Mojon [5].

[10] This 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.

incentive toward riskier investments increase. Statistical and anecdotal information confirm that financial institutions of various sorts (banks, conduits and SIVs, investment funds, insurance companies, etc.) on both sides of the Atlantic became riskier, in the pre-crisis years, due to excessive leverage. Ample availability of funding induced banks to acquire riskier loans: a striking example of that is the issuance of mortgage loans to individuals without employment or income (so-called NINJA loans).

The empirical evidence on these transmission channels has grown fast in recent times. So far the analysis has focused on micro-survey data and on a panel dimension. Maddaloni and Peydró Alcalde [19] use evidence from a euro area lending survey to see whether monetary policy influences the lending practices of banks. The survey allows 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. [3]) 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 – as one would expect, since lower interest rates on impact improve the financial condition of borrowers via changes in the value of collateral – but increases it over time. A plausible interpretation is that while the risk of *existing* loans is *positively* related to the level of the policy-determined interest rate, the risk of loans that are *issued subsequently* to the increase of such rate is *negatively* related to it, because the lending behavior of the bank changes. Measures of the average risk of loans combine the two elements, hence one tends to observe a switch in sign between the short and the long run.

In view of the possibility of these interacting dynamic effects, empirical evidence of the risk taking channel on macro-time series can be of considerable interest, but has so far been missing. In the next session we move a step forward in the direction of testing the risk taking channel at macro level[11].

3 Time series evidence

In this section we report time series evidence on the effect of monetary policy on bank risks, trying also to shed light on the two channels through which monetary policy can affect bank risk: funding behavior vs. lending behavior.

We use a standard orthogonalized VAR model, with monthly US data over the period 1985 to 2008. We exclude the periods after 2008, where our monetary policy indicator – the Federal Funds rate – is constant at zero, and when the monetary policy stance is probably better proxied by other (non-standard) indicators. We adopt, with modifications, the specification used by Bloom [8] (see also Bloom et al. [9]). The VARs include a small set of variables characterizing the macro-economy; the real sector is proxied by the ISM PMI index, a widely used composite indicator of manufacturing performance[12] and by total non-farm industrial employment. On inflation we include CPI and commodity price inflation, the latter in order to account for the global component of price dynamics. Besides monetary policy (proxied, as mentioned already, by the federal funds rate), all other variables included in the model are risk measures: we distinguish between funding risk and lending risk as follows (details on the data are contained in the Data Appendix):

- *Funding risk* is proxied by the ratio of total market-based bank funding to total bank

[11] The aggregate time series perspective can be important also for two additional reasons. First, to verify how significant are these risk-inducing effects at the macro level. Secondly, time series evidence allows us to consider the endogenous response of monetary policy: VAR evidence would indeed allow us to verify whether the endogenous response of monetary policy can neutralize or, on the contrary, encourage, risk taking behavior.

[12] See http://www.investopedia.com/university/releases/napm.asp#axzz23cTGf96n for more information on this index.

assets. The numerator is obtained by subtracting from total bank liabilities total customer deposits; the idea behind is that customer deposits, while being in principle callable on demand, in practice have a very high average duration and hence can be considered a stable form of funding. Other liabilities, that have grown sharply in recent times, consist of very short term revolving funding instruments like short CDs, repos, asset backed instruments and the like, carrying a non-contingent contractual return and subject to roll-over risk. These funding sources are subject to sudden withdrawal if market confidence deteriorates.

- *Lending risk* is proxied by the percentage of firms tightening their credit standards on loans to large and medium-sized enterprises. The idea behind this variable, obtained from the Fed survey of business lending, is that a tightening of credit standards by loan officers is usually driven by a perception of increased borrowers' risk, and therefore the former can be used as proxy of the latter. This variable, however, exists only at quarterly frequency and hence we used it only to conduct robustness checks on the results obtained with monthly data, as well as to obtain an estimate (on quarterly data only) of the effect of monetary policy on bank asset risk only, separate from that on bank funding risk.

- Finally, we use a proxy of *total bank risk*, logically including both components just mentioned. As proxy we use the realized volatility of a bank stock price index, calculated as the average daily absolute return of the index over each month.

The three measures are meant to identify possible channel of transmission of monetary policy to bank risk, respectively via the liability side, the asset side and both sides of the balance sheet. In particular, we expect that, if there exist a "risk taking channel" of monetary policy running via the funding side, the first and last of the above proxies should decline when monetary policy is tightened. If instead a risk taking behavior exists only on the lending side, then the last two should show a significant decline. If no risk taking channel to banks exist, none should be significant.

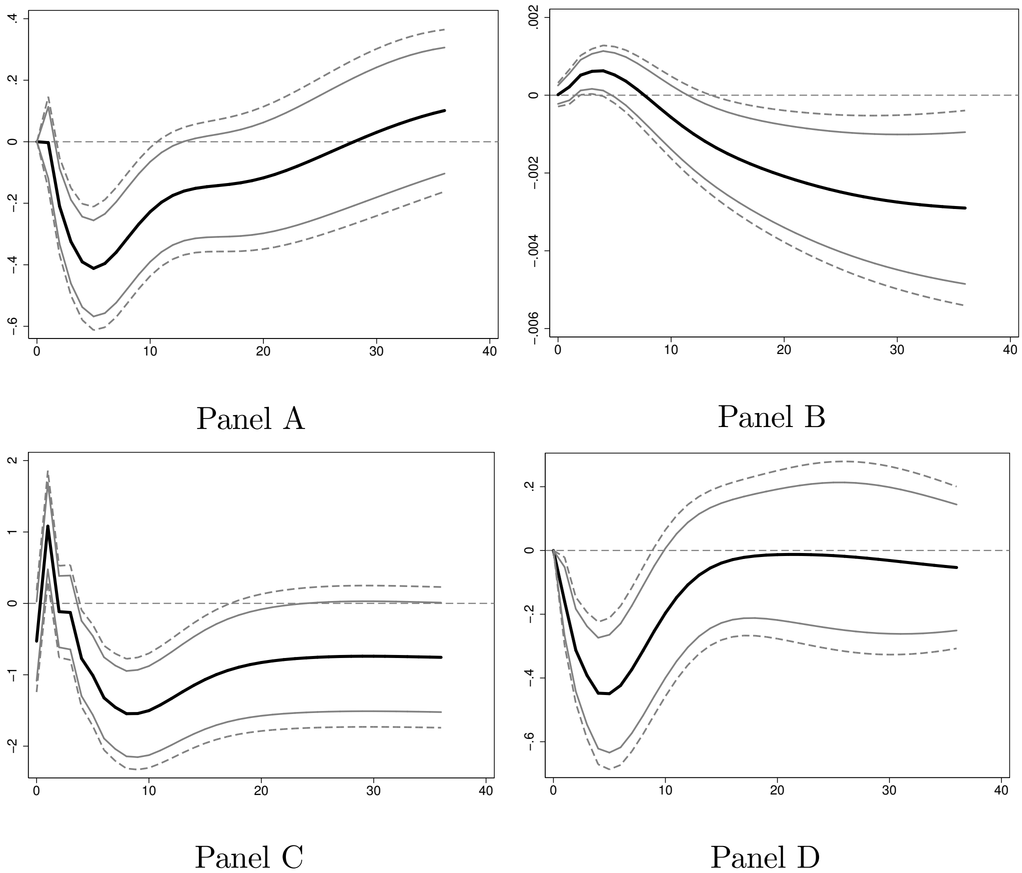


FIGURE 1: Impulse response of output to monetary contraction (A), of bank risk to a monetary contraction (B), of bank funding risk to a monetary contraction (c), and of output to bank risk (C)

Figure 1 shows a few results. The a contractionary monetary shock has the expected signs on real output (panel A): the PMI index declines significantly for about a year (confidence bands at 90 and 95 levels are shown in the charts) and, less significantly, also for the next year or so[13]. Concerning measures of bank asset risk, the impulse responses estimated at quarterly frequency were never significant, hence results are not reported. By contrast, the monetary contraction significantly reduces bank funding risk after about 12 months, confirming the existence of a "risk-taking channel" on the funding side (panel B).

[13]Inflation (not shown) drops on impact and rises subsequently. The fact that inflation tends to be positively correlated with interest rate increases at 12-18 months horizon into the future is probably due to the fact that the Fed responds systematically to expected future inflation, as required by its mandate.

At short term horizon, however, the effect is positive; this can be explained considering that the return on market based funding instruments adjusts more quickly to changes in policy rates than that of traditional customer deposits; hence its share tends to increase because its demand increases. This is consistent with the evidence on money demand, showing that the short term negative interest rate elasticity of narrowly defined monetary aggregates is larger in absolute value than that of broadly defined aggregates. Next, note that our measure of overall bank risk displays a response profile broadly consistent with that of our funding risk measure; positive in the short run, negative and significant at longer lags (panel C). This, in combination with the fact that the response of risk on the asset side is not significant, suggests that the response of bank risk to changes in policy rates is driven by what happens to the liability side, specifically by the share of market based (as opposed to more stable) sources of funding.

Finally, note that the measure of overall bank risk has a marked and significant impact on real output performance (panel D). This evidence is consistent with that presented by Bloom [8], according to which an increase in financial market risk is contractionary. This evidence uses measures of risk taken from the stock market: the hypothesis (examined through VAR evidence) is that an increase in asset risk affects firms' planning decision. We focus instead on bank risk and advance an alternative hypothesis, to which we return below.

We conducted a number of checks to verify the robustness of our results. We first changed the definition and the measurement of our risk variables, replacing them with alternative proxies[14]; the results remained stable. Finally, as already mentioned, 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 but available on request, are consistent in their interpretation with the results just described: we found evidence of causality from monetary policy shocks to the proxy for funding risk, but not to other measures of risk.

[14]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.

4 A macroeconomic model with fundamental bank runs

The financial side of our model features banks with an endogenous funding choice and endogenous risk of bank runs. Banks receive two sources of funding: demand deposits and bank capital. What we call, for simplicity, deposits are not traditional retail deposits, which usually are largely insured. They are uninsured short term funding instruments (for example, asset-backed securities, or repos), yielding a contractual non-contingent return set ex-ante, and subject to "run" in the form of roll-over risk. These two funding sources are combined to finance risky projects. demand deposits are subject to a non-contingent service constraint, which exposes banks to runs. If no run occurs, bank capitalists receive a rent, which compensates them for the risk of losses in the run states. The bank is administered by a bank manager, a "relationship lender " who by lending acquires a superior knowledge on the project's quality. The manager chooses the optimal funding structure (the optimal shares of demand deposits and bank capital) to maximize total expected returns to outside financiers. The bank manager's superior skills effectively create a moral hazard problem since the manager is tempted to withhold its technology, forcing a costly liquidation of the loan. Those incentives are disciplined in two ways. First, depositors can threat a run, a feature that effectively works as a discipline device. Second, the contractual agreement between the bank manager and the outside financiers takes the form of a bargaining arrangement in which the bank manager receives a fraction (depending on relative bargaining power) of the total returns: ex post bank managers have thus incentives to maximize total expected returns from the project.

The real sector of the model consists of a conventional macro model with nominal rigidities; in a model used for policy analyses, the latter are useful because they help better match the empirical evidence on monetary transmission on output and inflation.

4.1 Households

There is a continuum of identical households who consume, save, work and make portfolio decisions. Households save by lending to financial intermediaries, in the form of demand deposits and bank capital. To allow aggregation within a representative agent framework we assume that in every period a fraction γ of household members are bank capitalists and a fraction $(1-\gamma)$ are workers/depositors[15]. Hence households also own financial intermediaries. Bank capitalists remain engaged in their business activity next period with a probability θ, independent of history[16]. Workers are employed either in the production sector or in the banking sector, as bank managers; both return their earnings to the household. Bank dividends, earned by bank capitalists who remain in business, are assumed to be passed on to the new bank capitalists and reinvested in the bank (details below in section 5.2). 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 save and invest in bank demand deposits and bank capital (as explained above returns on ban capital are reinvested), both entail some risk. demand deposits, D_t, pay a gross nominal contractual return R_t. Due to the possibility of bank runs, the return on demand deposits is subject to a time-varying risk; the expected return on demand deposits is $R_t(1-\phi_t g_t)$, where ϕ_t is the probability of run and g_t is explained in Appendix A[17]. Households own the production sector, from which they receive nominal profits for an amount, Θ_t. Let T_t be net transfers to the public sector (lump sum taxes, equal to public expenditures). The budget constraint is[18]:

$$P_t C_t + T_t + D_t \leq W_t N_t + \Theta_t + \Xi_t + R_{t-1}(1-\phi_{t-1} g_{t-1}) D_{t-1} \tag{2}$$

[15] We could alternatively assume two set of households, one composed solely by risk averse workers and one composed solely by finitely lived and risk neutral bank managers. This alternative assumption would not affect the main channels of the monetary transmission mechanism in our model. The only difference would consist in the addition of a separate consumption function for bank capitalists. Since bank capitalists consist of a small fraction of the population, their consumption would not quantitatively affect the dynamic of the real economy.

[16] This finite survival scheme is needed to avoid that bankers accumulate enough wealth to remove the funding constraint. A fraction $(1-\theta)$ of bank capitalists exit in every period, becoming workers, and a corresponding fraction of workers become bank capitalists every period, so that the share of bank capitalists, γ, and workers remain constant.

[17] Households could in principle invest their savings either lending directly to firms, or by acquiring bank deposits. In the first case, as uninformed investors they would be able to liquidate at most a fraction λ of their investment. As shown in the next section the bank can guarantee to the depositor, in case of run, a payoff at least equal to $\frac{(1+\lambda)(1-c)(R_t^A-h)}{2}$. In our benchmark parametrisation, the worse case return for the depositor if she invests in the bank is larger than the liquidation value λ, the depositor's outside option. This guarantees the depositor's participation in the contract.

[18] Note that the return from, and the investment in, bank capital do not appear in equation 2, because returns on bank capital are reinvested.

where W_t is the unitary wage and Ξ_t are total revenues earned by bank managers. Households choose the set of processes $\{C_t, N_t\}_{t=0}^{\infty}$ and demand deposits $\{D_t\}_{t=0}^{\infty}$, taking as given the set of processes $\{P_t, W_t, R_t\}_{t=0}^{\infty}$ and the initial value of demand deposits D_0 so as to maximize 1 subject to 2. The following optimality conditions hold:

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

$$U_{c,t} = \beta E_t \left[\frac{R_t}{\pi_{t+1}} (1 - \phi_t g_t) U_{c,t+1} \right] \tag{4}$$

where $\pi_{t+1} = \frac{P_{t+1}}{P_t}$. 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 demand deposits subject to a service constraint, and bank capitalists) and allocates them to entrepreneurs, who undertake capital investment[19]. Total bank funds, L_t, are therefore allocated to finance the total value of capita investment, $Q_t K_{t+1}$ (where K_{t+1} is the aggregate stock of capital investment and Q_t is the re-sell price of the capital good, which will be derived endogenously in section 4.4.1; occasionally we will refer to Q_t as the asset price or the Tobin's Q). Firms finance investment fully with bank lending. 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 return accruing to the intermediary (bank) is subject to an idiosyncratic shock. As already mentioned, the bank manager maximizes the total expected return to both financiers; since funding markets are competitive, this is equivalent to maximizing the bank manager's return, see Allen and Gale [2]. To maintain banks managers incentives' to commit his technological skills depositors can

[19] To maintain consistency with the hypothesis of a relationship lender, we assume that each bank invests in one project or in a small cluster of projects. The bank manager can indeed acquire information only by monitoring consistently one or a small group of banks. This implies that ex ante we neglect the possibility of full projects' diversification. Notice however that equilibrium runs would materialize even if the bank invests in all projects as long as returns' correlation is different than zero. To maintain tractability we do not consider this case, which would nevertheless be a relevant one.

threat a run. It is assumed that depositors receive precise signals on the projects' returns[20]: when returns are too low, a collective action problem materializes and depositors run the bank. A run entails costly project liquidation, which also produces aggregate resource costs. Outside financiers and bank managers are also linked by a contractual agreement, according to which bank managers receive ex post a share of total expected returns. Linking bank managers' fee to the expected returns through the bargaining agreement helps to maintain managers' incentive to maximize expected returns. The presence of demand deposits (as opposed to other long terms deposit contracts) avoids the threat of renegotiation: any attempt of the bank manager to renegotiate the contract will set off a run, which by forcing costly liquidation also destroy's bank managers' residual claims[21].

Banks are heterogenous as they run projects whose realization is in general different. However, later on we will show that both the optimal share of demand deposits (and bank capital) and the returns accruing to outside financiers are linear with respect to project value. This allows us to aggregate the equations characterizing the banking sector by simply taking expected values. Based on this and for sake of simplification we omit banks' individual subscripts from the start. Total funds, given by the sum of demand deposits (D_t) and bank capital, (BK_t), equal bank lending.

$$L_t = Q_t K_{t+1} = D_t + BK_t \tag{5}$$

The liability structure of the bank, measured by the deposit share, $d_t = \frac{D_t}{L_t}$[22], is determined by the bank manager on behalf of the external financiers. The manager sets the bank capital structure so as to maximize 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, set according to the bargaining contractual agreement.

Individual depositors are served sequentially and fully as they come to the bank for

[20] Alternatively one could think of depositors forming expectations about banks' returns: those expectations determine expected failure probabilities, thereby being fulfilled in equilibrium. See among others Kaminsky and Reinhardt [18], Calomiris and Mason [11] for evidence on the links between banks runs and fundamentals.

[21] See also Diamond and Rajan [15], [16] for a similar logic.

[22] 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, $\frac{L_t}{BK_t}$

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[23].

The bank asset side yields an expected return R_t^A, homogenous across banks (the link between the average return and the real economy is detailed below) but subject to an idiosyncratic shock x_t with a uniform distribution defined in the space $\{-h; h\}$ [24]. As explained above 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 $R_t^A + x$. If outside investors (depositors or bank capitalists) 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 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 demand deposits to the total cost of the project, d_t, and collects the funds. At time $t + 1$, the project's outcome is revealed, the bank manager acquires the return R_t^A, 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. Notice that this costs materializes only in the event that a run occurs.

[23] As explained so far bank runs in this model work as discipline devices, hence, as also pointed out in Diamond and Rajan [16], in this context deposit insurance is inefficient as it distorts banks' incentives.

[24] In Angeloni and Faia [4] 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 us to work out an analytical solution of the deposit ratio and to gain intuition regarding the main mechanisms.

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[25]. Therefore, depositors get

$$\frac{(1+\lambda)(1-c)(R_t^A + x_t)}{2} \tag{6}$$

and the bank manager gets:

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

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 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:

$$\frac{\left\{\left[(R_t^A + x_t) - R_t d_t\right] - \left[\lambda(R_t^A + x_t) - R_t d_t\right]\right\}}{2} = \frac{(1-\lambda)(R_t^A + x_t)}{2} \tag{8}$$

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

[25] In Angeloni and Faia [4] 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.

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

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:

$$\frac{1}{2h}\int_{-h}^{R_t d_t - R_t^A} \frac{(1+\lambda)(1-c)(R_t^A+x_t)}{2} dx_t + \frac{1}{2h}\int_{R_t d_t - R_t^A}^{\frac{R_t d_t}{\lambda} - R_t^A} \frac{(R_t^A+x_t)+R_t d_t}{2} dx_t + \tag{9}$$

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

It Appendix B we show that the value of d_t that maximizes equation 9 is comprised in the interval $\lambda\frac{R_t^A+h}{R_t} < d_t < \frac{R_t^A+h}{R_t}$. In this zone (see region D in our Appendix B), the third integral in the equation vanishes and the expression reduces to:

$$\frac{1}{2h}\int_{-h}^{R_t d_t - R_t^A} \frac{(1+\lambda)(1-c)(R_t^A+x_t)}{2} dx_t + \frac{1}{2h}\int_{R_t d_t - R_t^A}^{h} \frac{(R_t^A+x_t)+R_t d_t}{2} dx_t \tag{10}$$

The above function is a piece-wise concave function (see graph in appendix B), hence the second order condition is satisfied. Differentiating and solving for d_t yields the following equilibrium condition:

$$d_t = z\frac{R_t^A+h}{R_t} \tag{11}$$

Where $z = \frac{1}{2-\lambda+c(1+\lambda)}$. 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 10. 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 10. 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 10. 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 $R_t^A + h$. [26]

Note that the sources of deviation from a frictionless Modigliani-Miller world in our model are given by the relationship lender's advantage, $(1-\lambda)$ and the cost of run, c. If the first is zero ($\lambda = 1$), the bank manager's payoff vanishes and the problem no longer has a closed-form solution given by equation 11. If, moreover, $c = 0$, the capital structure of the bank has no effect on the value of the bank: the expected return for its investors, depositors and bank capitalists, equals R_t^A regardless of the value of d_t.

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) 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 equation 11 we derive an expression for total bank capital as:

$$BK_t = (1 - z\frac{R_{A,t} + h}{R_t})Q_t K_{t+1} \tag{12}$$

The last equation shows that our model also features a traditional banks' balance sheet channel: a fall in the policy rate, by raising asset prices also helps to boosts projects and banks' balance sheet values. An increase in the aggregate project value, $Q_t K_{t+1}$, induces banks to increase external finance, both in the form of demand deposits and bank capital. As explained above, following a fall in the policy rate, banks in our model tend to increase the share of demand deposits more than proportionally compared to bank capital. Such a

[26] 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 $\frac{1}{2h}\left(\int_{R_t d_t - R_t^A}^{h} \frac{1}{2} dx_t\right) R_t = \frac{1}{2h}\left(\frac{R_t^A + h - R_t d_t}{2}\right) R_t$. Equating to zero the sum of these effects and solving for d_t yields equation 11.

shift will also increase the probability of banks' runs as we show next.

Finally, a our model allows us to compute the probability of occurrence of bank runs which is defined as follows:

$$\phi_t = \frac{1}{2h} \int_{-h}^{R_t d_t - R_t^A} dx_t = \frac{1}{2}\left(1 - \frac{R_t^A - R_t d_t}{h}\right) \tag{13}$$

We will refer to ϕ_t also as bank riskiness. Notice that a fall in the policy rate R_t raises bank riskiness if it reduces R_t^A, since $z<1$, as can be seen by substituting equation 13. The negative relation between bank riskiness and the policy rate captures the essence of the risk taking in our model. A fall in the policy rate lowers the cost of short term funding. This induces the bank manager to shift toward short term funding as opposed to bank capital, which instead comes along with the additional rents extractions. Certainly the bank managers must balance the benefits of cheaper external funding with the costs of an increase in bank riskiness: on balance however it will prove convenient to increase the share of short term lending, leading ex post to higher risks of bank runs. Although the bank manager acts optimally from an individual point of view, higher probability of bank runs has ex post social resource costs, given by the expected losses ensuing projects' liquidation: atomistic bankers do not internalize such social costs, thereby they leverage more than it would be optimal[27].

4.3 Bank capital accumulation

After remunerating depositors and paying the fee to the manager, a return accrues to the bank capitalist as retained earning. Bank capitalists who remain in business accumulate all their returns. Bank capital accumulates from retained earnings as follows (again individual subscripts are omitted since aggregation does not change the shape of the aggregate bank capital accumulation)[28]:

[27] Angeloni and Faia [4] provide a normative analysis of monetary policy and prudential regulation.

[28] We assume that bank capitalists who exit business in every period transfer their wealth to capitalists who remain in business. Hence the aggregate wealth also includes an additional term (which, to facilitate notation, we do not report in the equations of the main text): $\Sigma_t = \gamma BK_{t-1}$. This term is parametrized so that bank net worth never falls below zero.

$$BK_t = \frac{\theta}{\pi_t}[BK_{t-1} + R_t^{BK} L_t] \tag{14}$$

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. R_t^{BK} can be derived from equation 10 as follows:

$$R_t^{BK} = \frac{1}{2h} \int_{R_t d_t - R_{A,t}}^{h} \frac{(R_t^A + x_t) - R_t d_t}{2} dx_t = \frac{(R_t^A + h - R_t d_t)^2}{8h} \tag{15}$$

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 15 into 14:

$$BK_t = \frac{\theta}{\pi_t}[BK_{t-1} + \frac{(R_t^A + h - R_t d_t)^2}{8h} L_t] \tag{16}$$

The bank capital structure depends on several counterbalancing factors. One can interpret equation 12 as a "demand" for bank capital given the volume of loans L_t and the interest rate structure (R_t, R_t^A), while equation 16 can be seen as a "supply" of bank capital in the following period.

4.4 Intermediate Good Producers

Given that our focus is on the analysis of the monetary transmission mechanism, we also allow for non neutral effects of monetary policy; to that aim we introduce nominal rigidities, by assuming quadratic adjustment costs on prices. Final goods in this economy are obtained by assembling, though a conventional Dixit Stiglitz aggregator, intermediate goods. Each firm i in the intermediate good sector 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:

$$E_0\{\sum_{t=0}^{\infty} \Lambda_{0,t}[P_t(i)Y_t(i) - (W_t N_t(i) + Z_t K_t(i)) - \frac{\vartheta}{2}\left[\frac{P_t(i)}{P_{t-1}(i)} - \pi\right]^2 P_t]\} \tag{17}$$

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 as obtained from the Euler condition, 4.

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:

$$\frac{W_t}{P_t} = mc_t A_t F_{n,t}; \frac{Z_t}{P_t} = mc_t A_t F_{k,t} \tag{18}$$

$$\begin{aligned} 0 &= U_{c,t} Y_t \tilde{p}_t^{-\varepsilon}((1-\varepsilon) + \varepsilon mc_t) - \vartheta \left[\pi_t \frac{\tilde{p}_t}{\tilde{p}_{t-1}} - 1\right] \frac{\pi_t}{\tilde{p}_{t-1}} U_{c,t} + \\ &\quad + \vartheta E_t\{\left[\pi_{t+1}\frac{\tilde{p}_{t+1}}{\tilde{p}_t} - 1\right] U_{c,t+1}\pi_{t+1}\frac{\tilde{p}_{t+1}}{\tilde{p}_t^2}\} \end{aligned} \tag{19}$$

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 19 takes the following form:

$$\begin{aligned} U_{c,t}(\pi_t - 1)\pi_t &= \beta E_t\{U_{c,t+1}(\pi_{t+1} - 1)\pi_{t+1}\} + \\ &\quad + U_{c,t} A_t F_t(\bullet)\frac{\varepsilon}{\vartheta}(mc_t - \frac{\varepsilon - 1}{\varepsilon}) \end{aligned} \tag{20}$$

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.

Using the equation for labour supply, 3, and for labour demand, 18, we can derive at this stage also the labour market equilibrium condition, which reads as follows:

$$-\frac{U_{n,t}}{U_{c,t}} = mc_t A_t F_{n,t} \tag{21}$$

4.4.1 Capital producers

Investment decisions are taken by a sector of capital produces which faces adjustment costs: the latter are introduced to obtain a time-varying price of capital, namely a conventional Tobin's Q. 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:

$$K_{t+1} = (1-\delta)K_t + \phi(\frac{I_t}{K_t})K_t \tag{22}$$

where $\phi(\bullet)$ is increasing and convex. Define Q_t as the re-sell price of the capital good. Capital producers maximize profits $Q_t\phi(\frac{I_t}{K_t})K_t - P_t I_t$, implying the following optimal price of assets:

$$Q_t\phi'(\frac{I_t}{K_t}) = P_t \tag{23}$$

.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):

$$Y_t^k \equiv Z_t + Q_t((1-\delta) - \phi\prime(\frac{I_t}{K_t})\frac{I_t}{K_t} + \phi(\frac{I_t}{K_t})) \tag{24}$$

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}^A:

$$\frac{R_{t+1}^A}{\pi_{t+1}} \equiv \frac{Y_{t+1}^A}{Q_t} = \frac{mc_{t+1}A_{t+1}F_{k,t+1} + Q_{t+1}((1-\delta) - \phi\prime(\frac{I_{t+1}}{K_{t+1}})\frac{I_{t+1}}{K_{t+1}} + \phi(\frac{I_{t+1}}{K_{t+1}}))}{Q_t} \tag{25}$$

Equation 25 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.

4.5 Official sector and market clearing

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

$$\ln\left(\frac{1+R_t}{1+R}\right) = \left[\phi_\pi \ln\left(\frac{\pi_t}{\pi}\right) + \phi_y \ln\left(\frac{Y_t}{Y}\right)\right] + m_t \tag{26}$$

All variables at the denominator, without time subscript, are the target or steady state. The variable m_t is a monetary policy shock whose process is described in the calibration section.

The government runs a balance budget and uses lump sum taxation to finance exogenous government expenditure, hence $T_t = G_t$.

Equilibrium in the final goods market requires that the production of the final good equals private consumption, investment, public spending, and the various resource costs. The combined resource constraints, inclusive of government budget, reads as follows:

$$Y_t - \Omega_t = C_t + I_t + G_t + \frac{\vartheta}{2}\left(\pi_t - 1\right)^2 \tag{27}$$

In the above equation, G_t is government consumption of the final good which evolves exogenously (see calibration section) and is assumed to be financed by lump sum taxes. The term $\frac{\vartheta}{2}\left(\pi_t - 1\right)^2$ represents the aggregate costs associated with the price adjustment process. The term $\Omega_t = \frac{1}{2h}\int\limits_{-h}^{R_t d_t - R_t^A} cR_t^A Q_t K_{t+1} dx_t$, represents the expected cost of project liquidation in the event of a run; it corresponds to the society's resource loss due to bank risk, in expected terms.

4.5.1 Definition of Competitive Equilibria

Definition. *For a given sequence of nominal interest rate* $\{R_t\}_{t=0}^{\infty}$*, for given initial conditions on asset evolution* $\{K_0, D_0, BK_0\}_{t=0}^{\infty}$ *and for a given set of exogenous processes* $\{A_t, G_t, m_t\}_{t=0}^{\infty}$ *a determinate competitive equilibrium for this economy is a sequence of allocations and prices* $\left\{C_t, N_t, d_t, BK_t, I_t, K_{t+1}, Y_t, \pi_t, mc_t, Q_t, R_t^A\right\}_{t=0}^{\infty}$ *which satisfy equations (4), (21),(11),(20),(23),(25),(16),(22),(27),(5) and* $Y_t = A_t F(N_t, K_t)$*.*

The equations above summarize the equilibrium conditions for our economy. Equations (4), (21) are the optimality conditions for the consumer's optimization problem, equations (11) is the optimality condition for the bank's optimization problem, equations (20),(23),(25) solve the firms' optimization problem, equations (16),(22) are the wealth accumulation equations and equations (27),(5) are the technological constraints.

In the quantitative simulations the model is solved in first-order approximation when discussing the impulse response functions and in second order approximations when discussing the results on asset price and output volatilities. The first order approximation allows to compare the impulse response functions with the VAR equivalent, which are linear. The second order approximations allows us to take into account the effects of model non-linearities on the asset price volatilities. In both cases the model is approximated around the stochastic steady state characterized by the long run distribution of bank projects' idiosyncratic returns: details on the calibration of the probability distribution are given in the calibration section.

4.6 Transmission Channels in our Model: Balance Sheet, Fire Sales and Risk Taking

To understand the monetary transmission mechanism in our model it is useful, prior to present the numerical results, to discuss the channels that characterize our economy. Our banking model is indeed quite complex and features more than one channel.

On the one side, our banking sector features a traditional banks' balance sheet channel. Any fall in asset prices, Q_t, for instance reduces bank capital as per equation 12. This in turn produces a credit squeeze on impact.

Based on equation 16, also next period capital value is reduced, therefore implying a shrinking in next period lending as from the equation $Q_{t+1}L_{t+1} = D_{t+1} + K_{t+1}^B$. The reduced availability of lending induces a sale of banks' assets. The ensuing fall in investment triggers further falls in next period asset prices and this may produce a progressive negative spiral, akin to a fire sale. Fire sale externalities are also an important part of the transmission mechanisms occurring through the banking sector.

However, in addition to these linkages our banking sector features also a risk taking channel, given by the fact that low interest rates generate an increase in bank risks. The latter is a source of long run costs of expansionary policies. As discussed earlier at low interest rates banks are tempted to increase the share of demand deposits, therefore increasing leverage and bank riskiness. In the general equilibrium a fall in R_t triggers a fall in $R_{A,t}$, but the ratio $\frac{R_{A,t}}{R_t}$, increases, therefore inducing an increase in d_t and in br_t. The occurrence of bank runs is associated with project liquidation: hence an increase in br_t increases the resource costs. Furthermore an increase in the risk premium triggers, in the medium to long run period, a fall in asset prices and investment.

The interaction of those channels is the key determinant of the shock and monetary transmission channel in our model. More detailed discussion is contained in section 6.

4.7 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. 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 somewhat below 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. We take 0.4 as 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 pre-crisis values of the money market rate and the bank lending rate. In the US over the last 20 years, based on 30-year mortgage loans, the spread has been around 3 percent. This leads to a value of λ around 0.5. In the numerical simulations we have chosen a value of 0.45. 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. Finally, we use a benchmark value of the social cost of a bank run, c, of 0.1, equal to the direct costs of resolution estimated by James [17] on a sample of banks liquidated by the FDIC.

Shocks. The are three macro shocks in the model. 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 calibrated according to standard RBC processes: it evolves as an AR(1) of the following form $A_t = A_{t-1}^{\rho_a} \exp(\varepsilon_t^a)$, where the steady-state value A is normalized to unity, $\rho_a = 0.95$ and where ε_t^a is an i.i.d. shock with standard deviation $\sigma_a = 0.008$. We then have an additive disturbance to the interest rate set through the monetary policy rule. The monetary policy shock is assumed to be moderately persistent (coefficient 0.2), as argued by

Rudebusch [24]. 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. Finally, log-government consumption evolves according to the following exogenous process, $\ln\left(\frac{g_t}{g}\right) = \rho_g \ln\left(\frac{g_{t-1}}{g}\right) + \varepsilon_t^g$, where the steady-state share of government consumption, g, is set so that $\frac{g}{y} = 0.2$ and ε_t^g is an i.i.d. shock with standard deviation σ_g. In accordance with macro evidence for both the U.S. and Europe, we set $\sigma_g = 0.007$ and $\rho_g = 0.9$.

5 Model analysis and results

We analyse our model along two dimensions. First, we verify, by examining its impulse response functions[29], whether our model reproduces the empirical evidence we presented earlier. Second, to complete the assessment of the relationship between risk, monetary policy and macro transmission and performance, we analyze the effect of an increase in the volatility of projects' idiosyncratic shocks (h, the investment projects' risks in our model) on the long run level of bank riskiness and output and on the volatility of asset prices and bank returns. As explained below, our model is able to replicate the relations that characterize those variables in the data and in the past literature, but through a novel channel.

To begin with, to introduce the reader to the functioning of the model, Fig. 2 shows impulse responses to a persistent 1% productivity increase.

[29]The figures show impulse response functions obtained through first-order approximation of the model. This choice is motivated by the need to provide impulse responses which are consistent with those in the VAR, which is linear. Importantly, due to the endogenous nature of our bank risk, a risk taking channel materializes in our model as first order effect of a decrease in the nominal interest rate. On the contrary, the volatilities presented later in the paper are computed with second-order approximations to take into account the effect of nonlinearities and the full cost of risk in our model.

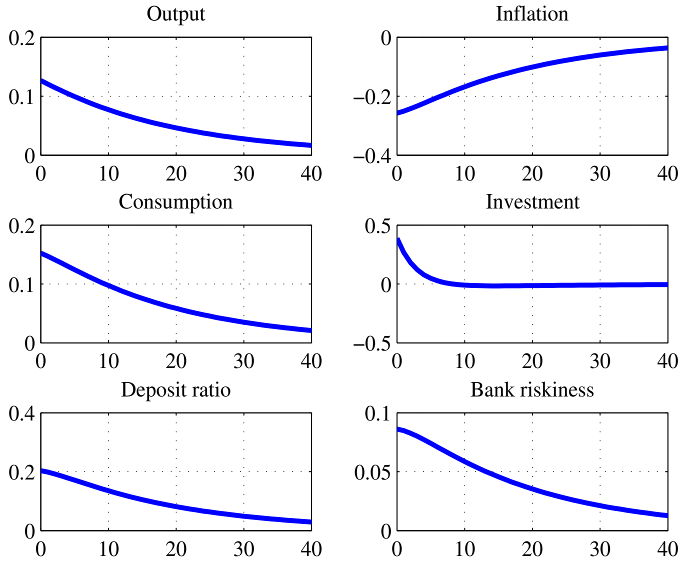


Fig. 2: Impulse response to a positive productivity shock

As expected output raises and inflation falls on impact, due to nominal rigidities. These are standard results common to most RBC or neo-Keynesian-type models. The ensuing fall in the policy rate, which is set according to a Taylor rule, triggers an increase in the deposit ratio and in bank riskiness, as per equation 11. This happens for two reasons. First, the increase in asset prices raises investment and the demand for bank loans. As a consequences banks require higher external funding, that can be provided through demand deposits and/or bank capital. The fall in the nominal interest rate also implies that demand deposits become a cheaper form of external finance, hence bank managers increase the fraction of lending financed by demand deposits. The ensuing increase in bank leverage comes along with an increase in the size of the run region and the probability of bank runs.

We now examine the transmission of a contractionary monetary policy shock. Fig. 3 shows impulse responses to a 1% short term interest shock; solid lines (blue) show our benchmark model with banking. As expected, output, investment and asset prices decline on impact. Due to nominal rigidities, aggregate demand falls. An increase in the policy rate reduces asset prices. In our model, by reducing banks' balance sheet values, the decrease in the asset price also induces a credit squeeze and a fall in investment (a balance sheet channel). The risk taking channel on the funding side works as follows. The fall in asset prices and investment triggers a fall of bank funding: this induces a fall in both D and BK. As demand deposits are now a relatively more expensive form of funding, the deposit ratio, hence bank risk, falls.

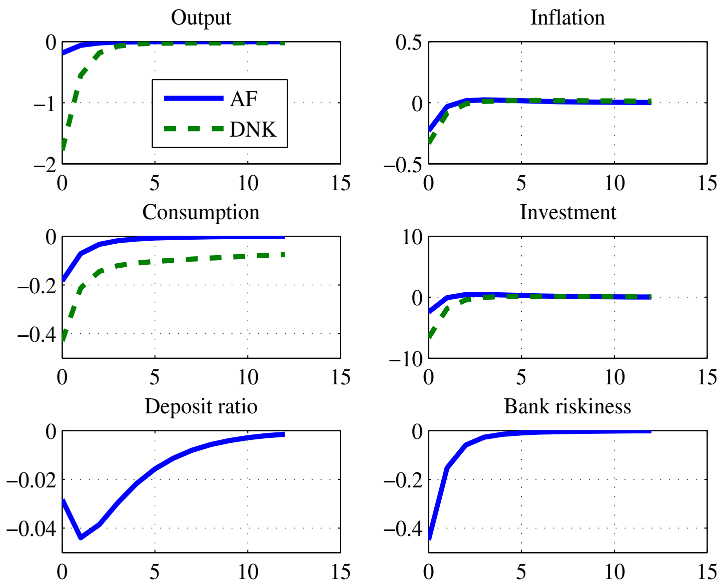


Fig. 3: Impulse response to a monetary restriction (two models)

To better highlight the mechanisms at work in our model we compare these results with those obtained with a standard dynamic neo-keynesian model without banks – dashed (green) lines. The comparison reveals that in our banking model the short term impact of a monetary policy shock is dampened. Bank risk in our model is contractionary; hence, an expansionary monetary policy, in presence of an increase in bank risk, increases output less than would be the case in absence of a risk taking channel. The fall in bank risk has indeed two effects in our model. First, it reduces the resource costs Ω, hence inducing an increase in total resources that tends to increase household consumption. Second, the decline in the bank deposit ratio results in an increase in the bank asset return R_t^A that is lower than the increase in the short term interest rate: this can be seen through equation 11. The dynamic of investment depends upon the dynamic of the return on capital, R_t^A: when the latter is dampened, the dynamic of investment is dampened too. This second effect is reminiscent of empirical analyses showing that relationship lending tends to protect borrowers from monetary shocks (e.g. Petersen and Rajan [22]). Notice that, contrary to our empirical evidence, there is no "J curve" in the behavior of bank risk to monetary policy: this is because our model does not distinguish between market-based and traditional deposit funding, plus bank capital, on the bank liability side, but only between deposit and bank capital.

5.1 The Link between Risk, Financial Market Volatility and the Macroeconomy

Our model sheds new light on the widely explored links between risk on the one side and financial performance (as summarized by volatility and long run level of asset prices) as well as macroeconomic performance (as summarized by volatility and long run level of output) on the other. Several papers have discussed the effect of an increases in asset risk (triggered by the arrival of "bad news") on the volatility and the long run level of asset prices and/or output. Generally speaking the literature finds that an increase in asset risk triggers an increase in the volatility of both asset price and output and a fall in their long run levels. These links have undergone much greater scrutiny after the financial crisis. The classic result of Campbell and Hentschel [12], that an increase in stock market volatility, induced by an increase in investment risk, is associated with higher returns and lower stock prices in equilibrium, has been re-examined recently, among others, by Bae, Kim and Nelson [7] and Bloom [8]. The first paper tries to identify causality, looking at whether it is asset risk, which by raising asset price volatility causes asset prices to decline (as also suggested by Campbell and Hentschel), or else it is the low level of stock prices that, by increasing leverage, drives stock market volatility up. In addition, Bloom [8] shows that an increase in financial risk increases output volatility and reduces its long run level. We re-examine those links within our model which features endogenous risk formation.

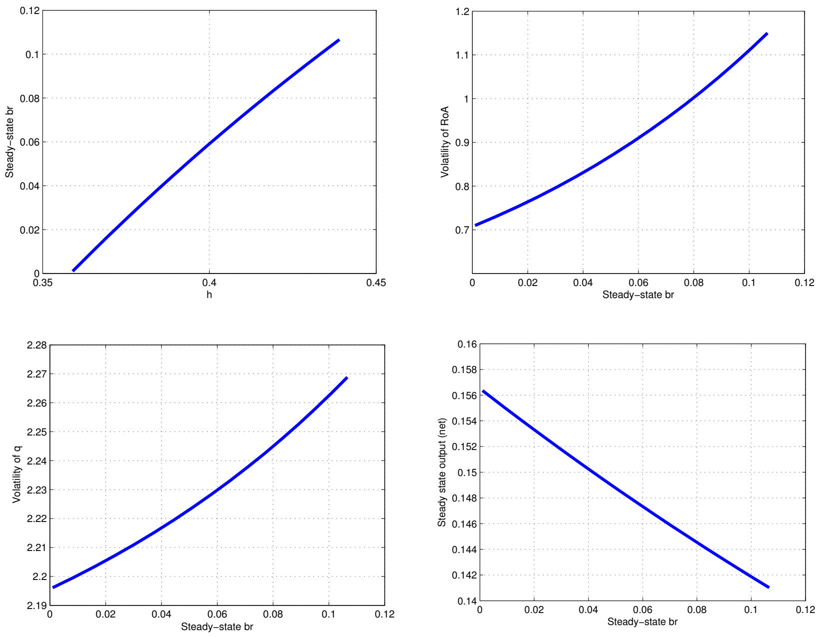


FIGURE 4: Mapping between project risk (h), bank risk, volatility of R_t^A, volatility of the asset price and steady state output

One appealing feature of our model is that we can distinguish between asset or projects' risk (which is captured by the volatility of shocks to projects' returns, h) and endogenous formation of bank risk (probability of bank runs). When projects' risk rises, depositors adjust their run region: such an adjustment process affects the availability of funding to bank, which in turn affects the availability of credit to the economy as well as the long run level and the dynamic of investment and output. To this purpose we examine the effect of an increase in the risk of projects returns (as captured by the idiosyncratic volatility h) on the long run levels and the business cycle volatilities for some variables, computed using second order approximations of the full model to account for first and second order effects of risk in our model[30].

Figure 4 shows long run levels of bank riskiness and output and the volatilities of asset returns (R_t^A in our model) and asset prices, Q_t.We see first, in panel 1, that an increase in h

[30]To compute volatilities we considered the set of shocks described in the calibration section.

raises bank risk in the long run (probability of runs). This happens for two reasons. There is first a direct effect: as the probability of extreme events raises, the runs region widens (see equation 13). Second an increase in h induces an increase in bank leverage, see equation 11: as the bank is more exposed to demand deposits, the probability of a run increases.

In the long run, higher risk is rewarded with higher return R^A (the steady state value of R_t^A increases): the higher cost of funding induces entrepreneurs to reduce the demand of funding, hence investment in the long run. This coupled with the increase in the log run resource costs of bank risk, Ω, reduces the long run level of output – panel 4 (expressed as percentage output loss relative to the case in which bank risks are zero).

Let's now examine the effects of such shift in risk on business cycle volatilities. To meet the higher level of long run returns, banks' funding and firms' credit availability shall increase by more in response to risk-increasing shocks. This amplified response translates into higher volatility of bank asset returns and asset prices, panels 2 and 3 (the values of these volatility are congruent with the data). This is in turn associated with higher volatility of output, investment and inflation (not shown).[31]

These results confirm links already noted in past literature, but also highlights a new channel that stems from the endogenous formation of risk: when investment project risk increases, more bank runs materialize. This destabilizes bank funding and investment (raising their volatility), and reduces output potential in the long run.

All together, these results can help interpret certain developments in the years prior to the crisis. A sequence of positive productivity shocks, alongside with expansionary monetary policy, increased bank leverage; the implication for bank risk was not appreciated immediately by market participants, as witnessed by the fact that credit spreads and ratings remained very favorable for a long period during the leverage buildup. The impact of the monetary expansion on output was positive. But in the end, when risks built up in the economy and became entrenched, they manifested themselves in the form of high risk spreads, high (downward) volatility of output and inflation. The model predicts, in addition, lower steady state output and investment.

[31] For low levels of bank risk, the volatility of output first declines before rising, as bank risk increases. This concave shape is due to the fact that higher bank risk reduces the volatility of the interest rate *net of bank risks*, which is the return relevant for consumer decisions in our model. Hence consumption volatility initially declines before rising. Instead, investment volatility rises monotonically in the whole range.

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.

We present new evidence linking monetary policy and bank riskiness through a risk taking channel: lowering policy rates raises bank riskiness, particularly on the funding side. We propose a model with banks runs and banks' risk taking that reproduces the main channels highlighted in the time series evidence. Overall, we highlight a new dimension of the monetary policy transmission that calls reflection upon the long run unintended consequences of protracted policy expansions and opens the avenue to a reconsideration of the optimal policy design in presence of financial risk.

References

[1] Allen, F. and D. Gale, (2000). "Bubbles and Crises." *Economic Journal*, 110, 236-255.

[2] Allen, F. and D. Gale, (2007). *Understanding Financial Crises*, Oxford University Press.

[3] Altunbas Y., L. Gambacorta and D. Marques-Ibanez, (2009). "An Empirical Assessment of the Risk-Taking Channel." BIS w.p..

[4] Angeloni, I. and E. Faia (2013). "Capital Regulation and Monetary Policy with Fragile Banks." *Journal of Monetary Economics,* 60,3, pp.3111-382.

[5] Angeloni, I., A. Kashyap and B. Mojon, (2003). *Monetary Policy Transmission in the Euro Area*, Cambridge University Press.

[6] Assenza, T. and Delli Gatti, D., (2013). "E Pluribus Unum: Macroeconomic modelling for multi-agent economies." *Journal of Economic Dynamics and Control*, vol. 37(8), pages 1659-1682.

[7] Bae, J., C. Kim and C. Nelson, (2007). "Why Are Stock Returns and Volatility Negatively Correlated?." *Journal of Empirical Finance,* vol. 14, January, pp. 41-58.

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

[9] Bloom, N., M. Floteotto and N. Jiaimovich, (2010). "Really Uncertain Business Cycles." Mimeo.

[10] Borio, C. and P. Lowe (2002). "Asset prices, financial and monetary stability: exploring the nexus." BIS Working Papers No 114.

[11] Calomiris, C. W. and J. R. Mason, (2003). "Consequences of Bank Distress During the Great Depression." *American Economic Review*, vol. 93(3), pages 937-947.

[12] Campbell, J. and L. Hentschel (1992). "An Asymmetric Model of Changing Volatility in Stock Returns." *Journal of Financial Economics* 31.

[13] Dell'Ariccia, G., L. Laeven and R. Marquez, (2011). "Monetary Policy, Leverage and Bank Risk-taking." CEPR Discussion Paper 8199.

[14] Diamond, D. W. and P. H. Dybvig, (1983). "Bank Runs, Deposit Insurance, and Liquidity." *Journal of Political Economy,* vol. 91(3), pages 401-19.

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

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

[17] James, C. (1991). "The Losses Realized in Bank Failures." *The Journal of Finance* Vol. 46, No. 4 (Sep.), pp. 1223-1242 .

[18] Kaminsky, G. L. and C. M. Reinhart, (1999). "The Twin Crises: The Causes of Banking and Balance-of-Payments Problems." *American Economic Review*, vol. 89(3), pp. 473-500.

[19] Maddaloni, A., Peydró Alcalde, J. L., 2010. Bank risk-taking, securitization, supervision and low interest rates: evidence from the euro area and the U.S. lending standards. ECB Working Paper, 1248.

[20] Mishkin, R. and J. Taylor, (2005). "The monetary transmission mechanism: an empirical framework." *Journal of Economic Perspectives*, 9, 4

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

[22] Petersen, M. and R. Rajan, (1994). "The Benefits of Lending Relationships: Evidence from Small Business Data." *Journal of Finance*, vol 49 n. 1, pp. 3-37.

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

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

7 Appendix A. Expected Loss on Risky demand deposits

When the probability of bank run is non-zero, the expected payoff on demand deposits is below the risk-less return R_t. Consider the payoff of demand deposits per unit of funds intermediated by the bank in two events: run for sure and no run (all other cases). In the first case the payoff 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 the expression for the probability of run ϕ_t, equation 13, as

$$\frac{(1+\lambda)(1-c)}{2}\int_{-h}^{R_t d_t - R_t^A}\frac{(R_t^A + x_t)}{2h}dx_t = \frac{(1+\lambda)(1-c)}{2}\left[\phi_t R_t^A + \frac{1}{2h}\frac{(R_t d_t - R_t^A)^2 - h^2}{2}\right]$$
$$= \phi_t \frac{(1+\lambda)(1-c)}{2}\left(R_t^A + \frac{R_t d_t - R_t^A - h}{2}\right)$$
$$= \frac{1}{4}\phi_t(1+\lambda)(1-c)(R_t d_t + R_t^A - h)$$

In the range of x_t in which the run does not occur, the payoff is equal to $R_t d_t$; its expected value is obtained multiplying it by the probability of the respective event, $(1-\phi_t)$.

Overall, the expected payoff on demand deposits per unit of intermediated funds therefore 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 demand deposits, relative to the no-default state, per unit of intermediated funds, is obtained by subtracting the above expression from $R_t d_t$, the contractual payoff

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

One can also calculate the expected return on demand deposits, i.e. the payoff per unit of demand deposits. This is equal to $R_t(1-\phi_t g_t)$, where $g_t = \frac{1}{4}(1+\lambda)(1-c)(R_t + \frac{R_t^A - h)}{d_t})$.

8 Appendix B. Optimal Deposit Ratio

In order to show that the value of d_t that maximizes the function 9 is equal to $\frac{1}{R_t}\frac{R_t^A + h}{2-\lambda+c(1+\lambda)}$, we divide the d_t space as follows:

- Interval A: $R_t d_t < \lambda(R_t^A - h)$;
- Interval B: $\lambda(R_t^A - h) < R_t d_t < R_t^A - h$;
- Interval C: $R_t^A - h < R_t d_t < \lambda(R_t^A + h)$;

- Interval D: $\lambda(R_t^A + h) < R_t d_t < R_t^A + h$;
- Interval E: $R_t^A + h < R_t d_t$.

We now analyse the function in each interval, in the following order: A, B, C, E, D. The last one is where we will show the global maximum to be located.

- Interval A: $R_t d_t < \lambda(R_t^A - h)$. The function reduces to $\frac{1}{2h}\int\limits_{-h}^{h} \frac{(1+\lambda)(R_t^A + x_t)}{2} dx_t$. This is independent of d_t, hence the function is flat and its level is equal to $\frac{1}{2} R_t^A (1 + \lambda)$.
- Interval B: $\lambda(R_t^A - h) < R_t d_t < R_t^A - h$. The function reduces to

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

  The first derivative is $\frac{R_t}{4h}\left[\frac{R_t}{\lambda} d_t - (R_t^A - h)\right]$ and the second derivative is $\left[\frac{1}{4h\lambda} R_t^2\right]$, both positive for all admissible parameter values. Hence in this interval the function is upward sloping and convex.

- Interval C: $R_t^A - h < R_t d_t < \lambda(R_t^A + h)$. The function is equal to

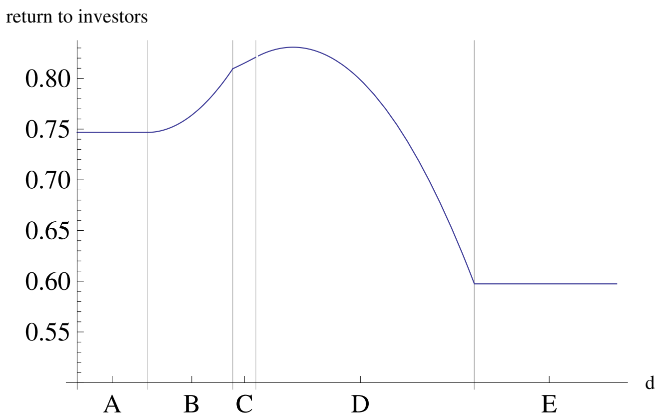
$$\frac{1}{2h}\int\limits_{-h}^{R_t d_t - R_t^A} \frac{(1+\lambda)(1-c)(R_t^A + x_t)}{2} dx_t \frac{1}{2h}\int\limits_{R_t d_t - R_t^A}^{\frac{R_t d_t}{\lambda} - R_t^A} \frac{(R_t^A + x_t) + R_t d_t}{2} dx_t + \\ + \frac{1}{2h}\int\limits_{\frac{R_t d_t}{\lambda} - R_t^A}^{h} \frac{(1+\lambda)(R_t^A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

  The first derivative is $\frac{R_t^2 d_t}{4h}\left[\frac{(\lambda-1)^2}{\lambda} - c(\lambda+1)\right]$ and the second is $\frac{R_t^2}{4h}\left[\frac{(1-\lambda)^2}{\lambda} - c(\lambda+1)\right]$; both are positive if and only if $\frac{(1-\lambda)^2}{\lambda} - c(\lambda+1) > 0$. The condition is satisfied if c is zero, or else if λ and c are sufficiently low. For example, $\lambda < 0.5$ and $c < 0.3$ are jointly sufficient. For our parameterization, this condition is comfortably satisfied.

- Interval E: $R_t^A + h < R_t d_t$. The function reduces to $\frac{1}{2h} \int\limits_{-h}^{h} \frac{(1+\lambda)(1-c)(R_t^A + x_t)}{2} dx_t$. This is independent of d_t, hence the function is flat and its level is equal to $\frac{1}{2} R_t^A (1+\lambda)(1-c)$. Note that the value of the function in this interval is lower than in interval A.

- Interval D: $\lambda(R_t^A + h) < R_t d_t < R_t^A + h$. In this interval the return to outsiders reduces to equation 10. Consider this equation in detail. A marginal increase in the deposit ratio has three effects. First, it increases the range of x_t where a run occurs, by raising the upper limit of the first integral; this effect increases the overall return to outsiders by $\frac{1}{2h}\left[\frac{(1+\lambda)(1-c)}{2} R_t d_t\right] R_t$. Second, it 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 return to outsiders is negative and equal to $-\frac{1}{2h} R_t^2 d_t$. Third, it increases the return to outsiders for each value of x_t where a run does not occurs; this effect is $\frac{1}{2h}\left(\int\limits_{R_t d_t - R_t^A}^{h} \frac{1}{2} dx_t\right) R_t = \frac{1}{2h}\left(\frac{h - R_t d_t + R_t^A}{2}\right) R_t$. Equating to zero the sum of the three effects and solving for d_t yields equation 11. Since the second derivative is negative, this is a local maximum. Note that this local maximum is within interval D if $\lambda < \frac{1}{2-\lambda+c(1+\lambda)} < 1$, a condition comfortably satisfied in our case. Given the shape of the function in the other intervals, this is also a global maximum. QED.

The graph below plots the function 9 against d_t, for the following parameter values:: $R_t^A = 1.03$; $R_t = 1.005$; $\lambda = 0.45$; $h = 0.45$; $c = 0.2$. For $h < 0.39$, interval C vanishes, unless λ declines sufficiently, but all other properties carry through and the global maximum remains in interval D, as described.



Graph 3

In this interval, the expected payoff to the capitalist, that enters in the bank capital accumulation equation, is equal to

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

9 Appendix C. Data Description

Variable name	Description
ISM index	Level of ISM index. Source 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 1985 – December 2008. 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