Financial Cycles with Heterogeneous Intermediaries

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Abstract

This paper develops a dynamic macroeconomic model with heterogeneous financial intermediaries and endogenous entry. It features time-varying endogenous macroeconomic risk that arises from the risk-shifting behaviour of financial intermediaries combined with entry and exit. We show that when interest rates are high, a decrease in interest rates can stimulate investment and increase financial stability. In contrast, when interest rates are low, further stimulus can increase systemic risk and induce a fall in the risk premium through increased risk-shifting. In this case, the monetary authority faces a trade-off between monetary stimulus and financial stability.

Keywords: Banking, Macroeconomics, Monetary Policy, Risk-shifting, Leverage, Financial cycle.

1 Introduction

The recent crisis has called into question our modeling of the macro-economy and of the role of financial intermediaries. It has become more obvious that the financial sector, far from being a veil, plays a key role in the transmission of shocks and in driving fluctuations in aggregate risk. Macroeconomic models have long recognized the importance of capital market frictions for the transmission and the amplification of shocks.

In the literature featuring a collateral constraint (see e.g. Bernanke and Gertler (1989), Kiyotaki and Moore (1997)), agency costs between borrowers and lenders introduce a wedge between the opportunity cost of internal finance and the cost of external finance: the external finance premium. Any shock lowering the net worth of firms, households or banks can cause adverse selection and moral hazard problems to worsen, as the borrowers stake in the investment project varies, increasing the size of the external finance premium. As a result this leads to a decrease in lending and a fall in aggregate demand. Other recent models where a financial market friction plays a key amplifying role are Mendoza (2010), Mendoza and Smith (2014), Gertler and Kiyotaki (2015), Gertler and Karadi (2011) who use a collateral constraint in quantifiable frameworks[1]; Brunnermeier and Sannikov (2014) and He and Krishnamurthy (2013) where intermediaries cannot raise more than a fixed amount of equity; and Adrian and Shin (2010), Coimbra (2015) and Adrian and Boyarchenko (2015) where intermediaries face value at risk constraints. Financial intermediation not only plays a role in transmitting shocks but also in generating endogeneous increases in macroeconomic risk. In Brunnermeier and Sannikov (2014), for example, the economy may spend time in low asset price and low investment states. As a consequence of the existence of such suboptimal paths, macroeconomic risk may increase and will do so in periods where asset prices tend to be depressed and financial intermediaries underinvest. He and Krishnamurthy (2014) develop a model to quantify systemic risk, defined as the risk that financial constraints bind in the future.

This paper develops a simple general equilibrium model of monetary policy transmission with a risk-taking channel, in which the risk of intermediary default increases in periods of low volatility, low interest rate and compressed spreads, as observed during the pre-crisis period between 2003 and 2007. It provides a very precise definition of systemic risk as a state that would trigger generalized solvency issues in the financial sector that require government intervention. This is achieved by building a novel framework with a

[1] See also Gertler et al. (2012), Curdia and Woodford (2010), Farhi and Werning (2016), Aoki et al. (2016)

continuum of financial intermediaries heterogeneous in their value-at-risk constraints and a moral hazard friction due to limited liability that leads to risk-shifting. Value-at risk constraints are realistic features of the regulatory environment; they are embedded in Basel II and Basel III. They also reflect the practice of internal risk management in financial intermediaries, whether as a whole or for specific business lines within banks. Their heterogeneity may reflect heterogenous risk attitudes on the demand side or different implementations of regulatory constraints across institutions. We also assume deposit guarantees which are a widespread institutional feature.[2]

Value-at-risk constraints to model financial intermediaries have been used in a number of papers (see for example Danielsson, Shin and Zigrand (2010) or Adrian and Shin (2010, 2014)). Under a slightly different formulation of the value-at-risk constraint, Adrian and Boyarchenko (2015) describe an intermediary leverage cycle using a representative intermediary. In their model, leverage is highly procyclical and there is a trade-off between capital requirements, which reduce the risk of intermediary distress (defined as the constraint being binding), and the pricing of risk. Allen and Gale (2000) have shown that current and future credit expansion can increase risk shifting and create bubbles in asset markets, while Nuño and Thomas (2013) show that the presence of risk-shifting creates a link between asset prices and bank leverage, generating banking cycles. In Mendoza and Smith (2014) bankers determine their exposure to systemic shocks by trading off the risk-shifting gains due to limited liability of banks with the value of preserving their capital after a systemic shock. Like us, Fostel and Geanakoplos (2012) emphasize financial frictions and heterogeneity in investors to generate fluctuations in asset prices. One of the contributions of our paper is to study the interplay between risk-shifting and a heterogenous pool of intermediaries, thereby generating macroeconomic risk fluctuations and movements in the risk premium. Another contribution is to provide an intuitive and clearly defined measure of systemic risk. Finally, our paper is closely related to the growing literature on the risk taking channel of monetary policy (Borio and Zhu (2012), Bruno and Shin (2015)).

In the model, financial intermediaries collect deposits from households. Deposits are guaranteed by the government. They also invest and hold shares in the aggregate capital stock, which provide a risky return. Realistically, financial intermediaries have limited liability, which introduces a risk-shifting motive for investment and mispricing of risk. Those with a looser value-at-risk constraint will have a higher option value of default, which will generate pricing effects of entry and exit in risky financial markets. Both the aggregate capital stock and the risk premium of the economy are determined

[2] We are therefore abstracting from the important literature on bank runs (see e.g. Diamond and Dybvig (1983), Diamond and Kashyap (2016), Gertler and Kiyotaki (2015)).

by an *extensive margin* (which financial intermediaries lever) and an *intensive margin* (how much does each lever). This is the key novel feature of the model. Having variation in the intensive and the extensive margins generates both movements in aggregate leverage and asset pricing implications which are unusual in our models but seem to bear some resemblance with reality. While output and consumption seem to vary monotonically with the interest rate in short horizons, the underlying financial structure (and systemic risk) is non-monotonic. We explain here the basic economic intuition behind the workings of the model.

Our model features an endogenous non-linearity in the trade-off between monetary policy and financial stability. When the level of interest rates is high, a fall in interest rates leads to entry of less risk-taking intermediaries into the market for risky projects. The average intermediary is then less risky, so a fall in interest rates (i.e. a monetary expansion) has the effect of reducing systemic risk and expanding the capital stock. There is no trade-off in this case between stimulating the economy and financial stability. However, when interest rates are very low, a monetary expansion leads to the exit of the least risk-taking active intermediaries, which are priced out of the market by a large increase in leverage of the more risk-taking ones. This increases systemic risk in the economy despite positive effects on the aggregate capital stock, which is always increasing with a fall in interest rates. For this region, the intensive margin growth in leverage dominates the extensive margin fall as interest rates are reduced. In other words, the most risk-taking intermediaries increase their leverage so much that they more than compensate for the exit of the least risk-taking ones. There seems to be a clear trade-off between stimulating the economy and financial stability. Because of limited liability there will be over-investment, which will be even larger when the sector is dominated by more risk-taking intermediaries. Of course, the level of the interest rate is itself an outcome of the general equilibrium model and therefore a fixed point problem has to be solved. This non-linearity constitutes a substantial difference from the existing literature and is a robust mechanism coming from the interplay of the two margins. It provides a novel way to model the risk-taking channel of monetary policy analysed in Borio and Zhu (2012) and Bruno and Shin (2015). Recent empirical evidence on the risk-taking channel of monetary policy for loan books has been provided by Dell'Ariccia et al. (2013) on US data, Jimenez et al. (2014) and Morais et al. (2015), exploiting registry data on millions of loans of the Spanish and Mexican Central Banks respectively.

There are several important advantages of this novel set up to model financial intermediation. First, it takes seriously the risk-taking channel in general equilibrium and therefore allows the joint study of the usual expansionary effect of monetary policy -via a boost in investment - and of the macroeconomic financial stability risk, which is endogenous. Monetary policy is modeled as a reduction in the funding costs of financial intermediaries. An extension of the model featuring nominal variables is left for future work. Second, it is able to generate periods of low risk premium which coincide with periods of high endogenous macroeconomic risk. This happens when the market is dominated by more risk-taking intermediaries which also feature high levels of leverage. These periods also correspond to high levels of over-investment and inflated asset prices due to stronger risk-shifting motives. Thirdly, the model is highly tractable as it is crafted in a way such that the financial intermediation building block, although rich, can be inserted in a general equilibrium macroeconomic model. Fourthly, because the model introduces a simple way to model financial intermediary heterogeneity, it opens the door to a vast array of empirical tests of the monetary transmission mechanism based on microeconomic data on banks, shadow banks, asset managers, and so on. Indeed the heterogeneity can be in principle matched in the data with actual companies or business lines within companies and with their leverage behaviours.

Section 2 of the paper describes the model. Section 3 describes the main results in partial equilibrium, thereby building intuition. Section 4 shows the general equilibrium results and the response to monetary policy shocks. Section 5 looks at some empirical evidence for the cross-sectional implications of the model. The case of financial crises with costly intermediary default is analyzed in section 6 and section 7 concludes.

2 The Model

The general equilibrium model is composed of a representative household, a continuum of financial intermediaries, and a very simplified Central Bank and government. There is only aggregate risk, in the form of productivity shocks and monetary policy shocks.

2.1 Households and the production sector

The representative household has an infinite horizon and allocates her budget in order to consume a final good C_t^H. She finances her purchases using labour income W_t and returns from a savings portfolio. We assume that the household has a fixed labour supply and does not invest directly in the capital stock K_t.[3] It can either save using a one-to-one storage technology S_t^H and/or purchase deposits D_t^H from financial intermediaries at price q_t. Intermediaries use deposits, along with inside equity ω_t, to invest

[3]Given households are risk-averse and intermediaries are not (and also engage in risk-shifting), relaxing the assumption households cannot invest directly would make no difference in equilibrium unless all intermediaries are active and constrained. There are also little hedging properties in the asset, since the correlation of the shock to returns with wage income is positive. In the numerical exercises, it is never the case that all intermediaries are active and constrained, so to simplify notation and clarify the household problem we exclude this possibility by assumption.

in capital and storage. In Section 4 we will introduce monetary policy as a source of wholesale funding. Monetary policy will therefore affect the weighted average cost of funds for intermediaries.

The production function combines labour and capital in a typical Cobb-Douglas function. Since labour supply is fixed, we normalize it to 1. Output Y_t is then produced according to the following technology:

$$Y_t = Z_t K_{t-1}^{\theta} \tag{1}$$

$$\log Z_t = \rho^z \log Z_{t-1} + \varepsilon_t^z \tag{2}$$

$$\varepsilon_t^z \sim N(0, \sigma_z) \tag{3}$$

where Z_t represents total factor productivity. θ is the capital share, while ε_t^z is the shock to the log of exogenous productivity with persistence ρ^z and standard deviation σ_z. Firm maximization then implies that wages $W_t = (1-\theta)Z_t K_{t-1}^{\theta-1}$ and returns on a unit of capital $R_t^K = \theta Z_t K_{t-1}^{\theta-1} + (1-\delta)$.

The household program can then be written as follows:

$$\max_{\{C_t, S_t^H, D_t^H\}_{t=0}^{\infty}} E_0 \sum_{t=0}^{\infty} \beta^t u(C_t^H) \qquad \text{s.t.} \tag{4}$$

$$C_t^H + q_t D_t^H + S_t^H = D_{t-1}^H + S_{t-1}^H + W_t - T_t \qquad \forall_t \tag{5}$$

where β is the subjective discount factor and $u(.)$ the period utility function. T_t are lump sum taxes and S_t^H are savings invested in the one-to-one storage technology. Note that the return on deposits is risk-free despite the possibility of intermediary default. The reason is that deposits are guaranteed by the government, which may need to raise taxes T_t in the event intermediaries cannot cover their liabilities. Households understand that the higher the leverage of intermediaries, the more likely it is for them to be taxed in the future. However, they do not internalize this in their individual portfolio decisions since each household cannot by itself change aggregate deposits.

The return on storage is also risk-free, which implies that households will be indifferent between deposits and storage if and only if $q_t = 1$. Therefore, they will not save in the form of deposits if $q_t > 1$ and will not invest in storage if $q_t < 1$. In equilibrium, the price of deposits will be bounded by the unity return on storage, implying that $q_t \leq 1$. In the case $q_t = 1$, the deposit quantity will be given by financial intermediary demand, with the remaining household savings being allocated to storage.

2.2 Financial intermediaries

The financial sector is composed of financial intermediaries which fund themselves through inside equity and household deposits[4]. They use these funds to invest in the aggregate capital stock. They benefit from limited liability. Intermediaries are risk neutral and maximize expected returns subject to a Value-at-Risk constraint. To capture the diversity of risk attitudes among financial intermediaries, we assume that they are heterogeneous in the maximal probability of default α^i, the key parameter in the VaR constraint. The maximal probability of not being able to repay stakeholders (shareholders and depositors) varies across intermediaries and is distributed according to measure $G(\alpha^i)$ with $\alpha^i \in [\underline{\alpha}, \overline{\alpha}]$.

The balance sheet of intermediary i at the end of period t is as follows

Assets	Liabilities
k_{it}	ω_t^i
	$q_t d_{it}$

where k_{it} are the shares of the aggregate capital stock held by intermediary i; d_{it} the deposit amount which was contracted at price q_t and ω_t^i the inside equity.

2.2.1 Value-at-Risk constraint

Financial intermediaries are assumed to be constrained by a Value-at-Risk condition. This condition imposes that intermediary i invests in such a way that the probability its return on equity is negative must be smaller than an exogenous intermediary-specific parameter α^i.[5] The VaR constraint for intermediary i can then be written as:

$$\Pr(R_{t+1}^K k_{it} - d_{it} < \omega_t^i) \leq \alpha^i \tag{6}$$

The probability that net profit is smaller than starting equity must be less or equal than α^i. This constraint is not only in the spirit of the Basel Agreements (limiting downside risk and preserving an equity cushion), but Value-at-Risk techniques are also used by banks and other financial intermediaries to manage risk internally. It also has the property of generating procyclical leverage, which can be observed in the data as described in Geanakoplos (2011) and Adrian and Shin (2014) when equity is

[4]We will extend the funding options to include wholesale funding in section 4.

[5]Alternatively we could posit that the threshold is at a calibrated non-zero level of losses. There is a mapping between the distribution $G(\alpha^i)$ and such a level, so for any level we could find a $\tilde{G}(\alpha^i)$ that would make the two specifications equivalent given expected returns. We decide to use the current one as it reduces the parameter space.

measured at book value. Using a panel of European and US commercial and investment banks Kalemli-Ozcan et al. (2012) also provide evidence of procyclical leverage and of important cross-sectional variations across types of intermediaries. Heterogeneity in the parameter of the value-at-risk constraint can be rationalized in different ways. It could be understood as reflecting differentiated preferences for risk-taking or differentiated implementation of regulatory requirements. For example, the Basel Committee undertook a review of the consistency of risk weights used when calculating how much capital global banks put aside for precisely defined portfolio. When given a diversified test portfolio the global banks surveyed produced a wide range of results in terms of modeled value-at-risk and gave answers ranging from 13 million to 33 million euros in terms of capital requirement with a median of about 18 million (see Basel Committee on Banking Supervision (2013) p.52). Some of the differences are due to different models used, some to different discretionary requirements by supervisors and some to different risk appetites, as "Basel standards deliberately allow banks and supervisors some flexibility in measuring risks in order to accommodate for differences in risk appetite and local practices" (p.7).

2.2.2 Intermediary investment problem

We assume that intermediaries live for two-periods, receiving an endowment of equity ω in the first and consuming their net worth in the second, if it is positive. This is a simplifying assumption, but in the data, book value equity is indeed very sticky. We show in Figure (8) in the appendix the almost one-for-one correlation between size of assets at book value and debt for a sample of banks, as well as the correlation with book value equity. Balance sheet expansions and contractions tend to be done through changes in debt and not through movements in book value equity. Other papers in the literature assume that a maximum amount of equity can be raised (Brunnermeier and Sannikov (2014), He and Krishnamurthy (2014)) or that dividends pay outs are costly as in Jermann and Quadrini (2012).

Net worth consumed by financial intermediaries is denoted by c_t^i.[6] When net profits are negative, $c_t^i = 0$ and the government repays depositors as it upholds deposit insurance. This is a pure transfer, funded by a lump sum tax on households. Hence, in our model, households are forward-looking and do intertemporal optimization while most of the action in the intermediation sector comes from heterogenous leverage and risk-taking in the cross-section. This two-period modeling choice is made for simplicity and allows us to highlight the role of different leverage responses across financial intermediaries.

[6]When intermediary j is inactive, then $c_t^j = \omega$ as they consume the return of the storage technology is one.

Other papers in the literature have used related assumptions for example exogenous death of intermediaries in Gertler and Kiyotaki (2015) or difference in impatience parameters in Brunnermeier and Sannikov (2014).

Each intermediary will have to decide whether it participates or not in the market for risky assets (*participating intermediary* versus *non participating inetrmediary*) and, conditionally on participating whether it uses deposits to lever up (*active intermediary*) or just invests its own equity (*passive intermediary*).

Each intermediary is assumed to be a risk-neutral price taker operating in a competitive environment. It maximizes net worth over the next period by picking k_{it}, under the VaR constraint, while taking deposit prices q_t and asset return distributions $R_t^K(\varepsilon)$ as given. The program of a participating intermediary (i.e. an intermediary which invests in the risky capital stock) is given by:

$$V_{it}^p(K_t, Z_t) = \max \mathbb{E}_t^i \left[R_{t+1}^K k_{it} - d_{it}\right] \tag{7}$$

$$\text{s.t. } \Pr(R_{t+1}^K k_{it} - d_{it} < \omega_t^i) \leq \alpha^i \tag{8}$$

where α^i is the Value-at-Risk threshold, or the maximum probability of not being able to repay stakeholders fully.

Intermediaries can also choose not to participate in risky financial markets. In this case, they simply invest all their equity in the storage technology and collect it at the beginning of the next period. The value function of a non-participating intermediary is simply:

$$V_{it}^{np}(K_t, Z_t) = \omega_t^i \tag{9}$$

2.2.3 Limited liability

The expectations operator $\mathbb{E}_t^i$ is indexed by i because of limited liability. The presence of limited liability truncates the profit function at zero, generating an option value of default that intermediaries can exploit. For a given expected value of returns, a higher variance increases the option value of default as intermediaries benefit from the upside but are insulated from the downside. This means that for a given k_{it} and d_{it} we have that

$$\mathbb{E}_t \left[\max(0, R_{t+1}^K k_{it} - d_{it})\right] \equiv \mathbb{E}_t^i \left[R_{t+1}^K k_{it} - d_{it}\right] \geq \mathbb{E}_t \left[R_{t+1}^K k_{it} - d_{it}\right] \tag{10}$$

with the inequality being strict whenever the probability of default is strictly positive. Financial intermediary consumption c_t^i and deposit insurance transfers t_t^i are given by:

$$c_t^i = \mathbb{1}_{\pi^i \geq 0} \left(R_t^K k_{t-1}^i - d_{i,t-1} \right) \tag{11}$$
$$t_t^i = \mathbb{1}_{\pi^i < 0} \left(d_{i,t-1} - R_t^K k_{t-1}^i \right) \tag{12}$$

where $\pi_t^i \equiv R_t^K k_{t-1}^i - d_{i,t-1}$ are total portfolio returns net of liabilities. The indicator function selects the appropriate case depending on whether intermediary i can repay its liabilities or not. Total intermediary consumption C_t^I and aggregate transfers/taxes T_t are given by integrating over the mass of intermediaries:

$$C_t^I = \int c_t^i \, dG(\alpha^i) \tag{13}$$
$$T_t = \int t_t^i \, dG(\alpha^i) \tag{14}$$

For now we assume default is costless in the sense that there is no output cost when the government is required to pay deposit insurance. In another section, we will drop this assumption of costless default by having a more general setup that allows for a lower return on assets held by distressed intermediaries.

2.3 Business model choice and financial market equilibrium

Financial intermediaries are price takers, therefore the decision of each one depends only on the expected return on assets[7] and the cost of liabilities. Since the mass of an intermediary is zero, balance sheet size does not affect returns on the aggregate capital stock. Intermediary i will decide to participate in the market for risky assets whenever $V_i^p \geq V^{np}$. He will invest in storage otherwise and is then called a *non-participating intermediary*. This condition determines entry and exit into the market for risky capital endogenously.

There is however another important endogenous participation decision. Intermediaries which participate in the market for risky assets have to choose whether to lever up and, if they do, by how much. We will refer to the decision to lever up or not, i.e. to enter the market for deposits as the *extensive margin*. We will refer to the decision regarding how much to lever up conditional on levering up as the *intensive margin*.

Financial intermediaries which lever up are called *active* intermediaries. Active intermediaries have a *risky business model*. Financial intermediaries which participate

[7] Taking into account limited liability.

in the market for risky capital but do not lever up are called *passive* intermediaries. They have a *safe business model*. If the intermediary decides to lever up, it will do so up to its value-at-risk constraint [8]. Hence all *active* intermediaries (with risky business models) will be operating at their constraint.

Intensive margin (optimal investment for active intermediaries):

Let $Z_t^e \equiv \mathbb{E}(Z_{t+1}) = Z_t^{\rho^z}$. For an active intermediary i deciding to lever up, the following VaR condition will bind:

$$\Pr\left[\pi_{t+1}^i \leq \omega\right] = \alpha^i \tag{15}$$

After some straightforward algebra, we obtain the following:

$$\Pr\left[\varepsilon_{t+1} \leq \log\left(\frac{K_t^{1-\theta}}{q_t \theta Z_t^e}(1-\omega/k_{it}(1-q_t) - q_t(1-\delta))\right)\right] = \alpha^i \tag{16}$$

The leverage of an active intermediary i (defined as assets over equity) is given by:

$$\frac{k_{it}}{\omega} = \frac{(1/q_t - 1)}{1/q_t - (1-\delta) - \theta Z_t^e K^{\theta-1} \ \exp(F^{-1}(\alpha^i))} \tag{17}$$

Where $F^{-1}(\alpha^i)$ is the inverse cdf of the technology shock evaluated at probability α^i. Given the monotonicity of the cdf, leverage will be increasing in α^i.

Extensive margin (endogenous participations):

An intermediary can decide to invest in risky capital markets or in the storage technology. If they decide to not participate at all, then their value function is simply ω given the unit returns on storage.

If an intermediary decides to participate in the market for risky projects it then has to decide in favour of a risky business model (levered) or a safe business model (only invest its equity).

Let V^L denote the value function of *active* intermediaries (who decide to lever up) and V^N the one of *passive* ones.

$$V_{it}^L = \mathbb{E}_t^i[R_{t+1}^K k_{it} - d_{it}] \tag{18}$$
$$V_{it}^N = R_{t+1}^K k_{it}^N + \omega - k_{it}^N \tag{19}$$

[8]See Theorem 7.1 in Appendix B

with $k_{it}^N \in [0, \omega]$. Since there is no risk of defaulting on deposits if you have none, then there is no option value of default for non-levered intermediaries. This N group includes intermediaries who invest all their equity in capital markets ($k_{it}^N = \omega$) and intermediaries who do so only partially[9]. As shown in Theorem 6.1, all intermediaries in the L group are levering up to their constraint.

We can then use the condition $V_{it}^L = V_{it}^N$ to find the value $\alpha_t^j = \alpha_t^L$ for which intermediary j is indifferent between levering or not. Above α_t^L (looser value-at-risk constraints), all intermediaries will be levered up. For any levered intermediary i, the following condition holds:

$$\mathbb{E}_t^i \left[k_{it} R_{t+1}^K - d_{it} \right] \geq \omega \ \mathbb{E}_t \left[R_{t+1}^K \right] \tag{20}$$

where the left hand side is the expected payoff on the assets of intermediary i and the right hand side is the payoff when it invests only its equity ω in capital markets. Using the balance sheet equation $k_{it} = q_t d_{it} + \omega$, we can substitute for deposits, which leads to the following condition:

$$\mathbb{E}_t^i \left[k_{it} \left(R_{t+1}^K - 1/q_t \right) + \omega/q_t \right] \geq \omega \ \mathbb{E}_t \left[R_{t+1}^K \right] \tag{21}$$

For the marginal intermediary j, equation (21) holds with equality:

$$\mathbb{E}_t^j \left[k_{jt} \left(R_{t+1}^K - 1/q_t \right) + \omega/q_t \right] = \omega \ \mathbb{E}_t \left[R_{t+1}^K \right] \tag{22}$$

Since all active intermediaries will be at the constraint, we can combine equation (22) with equation (17) evaluated at the marginal intermediary. Moreover, $\mathbb{E}_t \left[R_{t+1}^K \right]$ is a function of Z_{t+1}^e and K_t therefore this equation defines an implicit function of the threshold VaR parameter α_t^L $(= \alpha^j)$ with variables (q_t, Z_{t+1}^e, K_t).

To close the financial market equilibrium, we need to use the market clearing condition.

$$K_t = \int_{\underline{\alpha}}^{\overline{\alpha}} k_{it} \ dG(\alpha^i) \tag{23}$$

The integral has three main blocks corresponding to active levered intermediaries (above α_t^L), passive intermediaries who invest all their equity in the risky capital stock (between α_t^N and α_t^L) and passive intermediaries who invest only a fraction (possibly zero) of their equity, the remainder being in storage (below α_t^N).

[9]Which occurs only if the intermediary has a sufficiently tight VaR constraint

We define $\alpha^N \equiv F\left(\frac{\delta}{\theta Z_t^e K_{t-1}^{\theta}}\right)$ as the marginal intermediary for whom the constraint would bind exactly if he invests all of its equity in risky capital markets ($k_{it} = \omega$). As long as $\mathbb{E}[R_{t+1}^K \geq 1]$, then $\forall \alpha^i \in [\alpha_t^N, \alpha_t^L]$, we have that $k_{it} = \omega$.

By plugging in the expressions for asset purchases and using the expression for α_t^N, equation (23) defines an implicit function of $(\alpha_t^L, q_t, Z_{t+1}^e, K_t)$. Since Z_{t+1}^e is a function of a state variable and intermediaries are price takers, these two implicit functions (market clearing (23) and extensive margin (22)) pin down the aggregate capital stock K_t and the marginal levered intermediary α_t^L, for a given deposit price q_t and expected productivity Z_{t+1}^e. In general equilibrium, the deposit price q_t will be determined in conjunction with the recursive household problem.

Systemic Risk

Very importantly, we can define in the model a precise and intuitive measure of systemic risk. A systemic crisis can be defined as a state of the world where all active intermediaries fail to repay in full all of their stakeholders (deposits and equity). Since all the risk in the model is aggregate, the probability of a systemic crisis is also the probability that the least risk-taking levered intermediary is being distressed, which is simply given by α_t^L.[10]

3 Partial equilibrium results

We look at the distribution of intermediary assets conditional on the price of deposits q_t and on expected productivity Z_t^e. In Figure (1), we show an example of the cross-sectional distribution of assets for three different values of the deposit rate. The calibration of the model is discussed in more detail in section 4.

In the three cases, the area below each line[11] is the aggregate capital stock $K_t = \int k_{it}\ dG(\alpha^i)$ and the vertical line showing a large drop in balance sheet sizes identifies the marginal levered intermediary α_t^L. To the left of the cutoff α_t^L, intermediaries are not levered, which corresponds to the more conservative VaR constraints. They have a "safe business model". To the right of the cutoff, the balance sheet size k_{it} increases with α_t^i. That is, the more risk-taking is the active intermediary, the larger will be its balance sheet for a given q_t and Z_t^e. Those intermediaries have a "risky business

[10] We could consider equally easily that there is a systemic crisis when a certain proportion of levered financial intermediaries are unable to repay depositors or when a certain fraction of total assets is held by distressed intermediaries.

[11] Assuming a uniform distribution for $G(\alpha^i)$ as in the baseline calibration.

model".

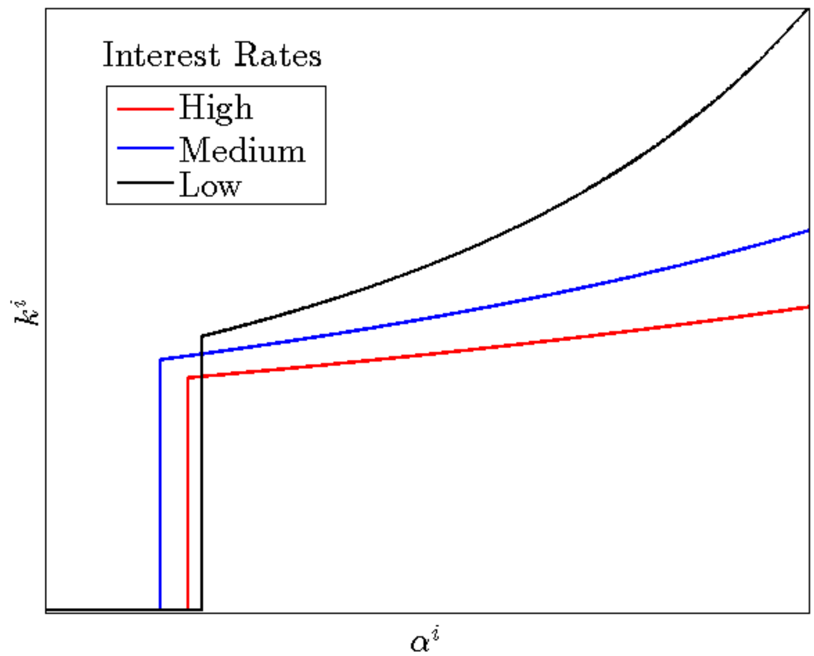

Figure 1: *Cross-sectional distribution of assets*

The graph also illustrates how the intensive and extensive margins affect the aggregate capital stock as the deposit interest rate changes. For the three cases displayed, as deposit rates fall (a rise in q), the intensive margin is always increasing. That is, for every intermediary that remains active, the balance sheet grows when the cost of leverage falls. This is because a lower rate reduces the probability of default for a given balance sheet size, as a lower rate reduces the cost of liabilities that needs repaying next period. Intermediaries expand their balance sheet up to the new limit and active intermediaries grow in size.

Perhaps less intuitively, the effect on the extensive margin is ambiguous. Depending on the level of interest rates, a fall in interest rates (a rise in q) can lead to more or fewer intermediaries choosing to lever. In Figure (1), for example, both the low and the high level of deposit rates have higher cutoffs than the medium level.

Non-linear trade-off between economic activity and financial stability.

Following a fall in interest rates, intermediaries expand their asset holdings raising the aggregate capital stock (intensive margin effect). We have however very interesting asymmetries depending on the *level* of the interest rate.

When the interest rate level is high, the lower cost of liabilities reduces the probability of default for a given balance sheet size. Hence all intermediaries with a risky business model can lever more (intensive margin); there are also positive returns for the marginal intermediary. More intermediaries therefore can lever and enter the market for deposits (extensive margin). In this case, the system becomes less risky since those intermediaries have a stricter value-at -risk constraint. There is therefore no trade-off between lower interest rate and financial stability.

When the interest level is low, the intensive margin effect of a decrease in interest rate is strong and the curvature of the production function leads to a decrease in expected asset returns which is enough to price out the intermediaries at the cutoff. The sign of the effect on α^L depends on whether the fall in asset returns is stronger than the fall in the cost of liabilities. In the case of initially low interest rates, a further fall (in those rates) leads to financial markets being characterized by fewer intermediaries choosing to lever. Those intermediaries are also larger and more risk-taking on average. There is a therefore a clear trade-off between a lower interest rate (which corresponds in equilibrium to an expansionary monetary policy) and financial stability.

Hence, as shown in Figure (1), when interest rates rise from low to medium to high, balance sheets become less heterogeneous and the difference between the most levered and the least levered intermediary falls. In contrast for low level of interest rates, we see an increase concentration of risk and of the skewness of leverage in the cross-section of intermediaries.

In Figure (2), the left graph plots the cutoff α_t^L as a function of deposit prices q_t (moving to the right is equivalent t a decrease in interest rate) for three different productivity levels, while the right graph does the same for the aggregate capital stock K_t. As we can see, K_t is monotonically increasing with q_t. As expected, the lower is the interest rate, the higher will be aggregate investment. However, the change in financial structure underlying the smooth increase in the capital stock is non-monotonic. As we can see from the left graph, the cutoff α_t^L first decreases and then goes up. When interest rates are high (q_t is low) a fall in interest rates leads to entry by less risk-taking intermediaries (a fall in the cutoff α_t^L) into levered markets. On the other hand, when interest rates are low, a fall in interest rates leads to a rise in the cutoff α_t^L, which means the least risk-taking intermediaries which were levered will now reduce their balance sheet size while more risk-taking intermediaries increase theirs.

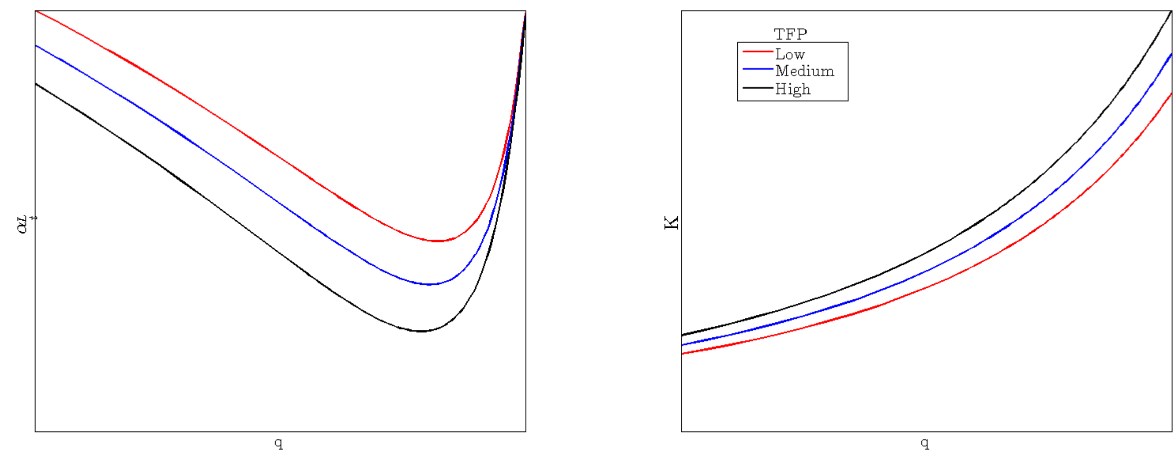

Figure 2: *Partial equilibrium in the financial sector*

Hence, interestingly, and unlike in the earlier literature, there is a potential trade-off between financial stability and monetary policy when interest rates are low, but not when they are high. During a monetary expansion, the cost of liabilities is reduced and the partial equilibrium results described above follow. The fact that risk-taking intermediaries are able to lever more can increase the capital stock and price out less risk-taking ones. This means that the financial sector becomes less stable, with risky assets concentrated in very large, more risk-taking financial institutions. There is also potentially large mispricing of risk[12], since these are the institutions that engage the most in risk-shifting. As a result, the effects of risk-shifting on over-investment described by Malherbe (2015) are amplified through the change in the extensive margin.

We illustrate this point in our partial equilibrium setting by doing a 100 basis points monetary expansion for different target rates. For this experiment, we assume a very simple monetary policy rule:

$$R_t = R_{t-1}^{\nu} \bar{R}^{1-\nu} \varepsilon_t^R \tag{24}$$

where $R_t = 1/q_t$ is the deposit rate. ε_t^R is a monetary policy shock, $\bar{R}$ the long-run level of interest rates and ν the persistence of the shock, calibrated[13] to 0.24. For simplicity, as we are not modeling the nominal side of the economy, we assume that the monetary

[12] Defined here as the difference between the market price and the price investors would be willing to pay in the absence of limited liability.

[13] Annualized value as estimated by Curdia et al. (2015)

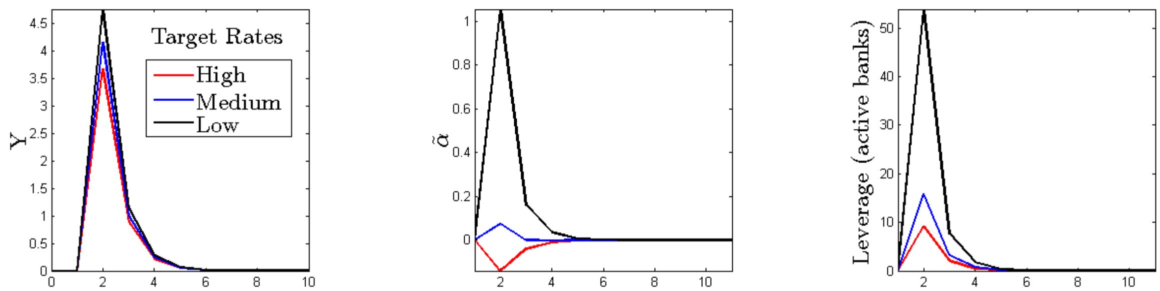

Figure 3: *Partial equilibrium IRF to a 100 basis points fall in deposit rates*

authority can directly affect the deposit rate. We relax this assumption in section 4 and show how it can be mapped into this exercise.

Results can be seen in Figure (3), plotted as percentage changes from their respective values at target rates $\bar{R}$.[14] The time period corresponds to one year and the state of the economy when the shock hits is the one corresponding to the target rates.

In the left graph we see that the rise in output seems to be slightly larger when rates are low, with the rise ranging from 3.4% to 4.5%. The monotonicity of K_t with respect to q_t ensures, as expected, that monetary policy stimulates investment and the capital stock in all cases. The behaviour of the cutoff α_t^L is, however, very differentiated. When the target rates are high, there is a small negative effect of a monetary expansion on the cutoff. That means that less risk-taking intermediaries enter levered markets and the average probability of intermediary default falls (although marginally so). In this case, there is no trade-off between financial stability and monetary expansion. This is definitely not the case when target interest rates are low. In that case, average leverage increases massively by 25% and the cutoff also rises. The large increase in leverage by very risk-taking intermediaries then prices out the less risk-taking ones at the margin, raising the average probability of default among levered intermediaries. For intermediate levels, we see that this effect is muted, with leverage increasing slightly more than in the first case and the effects on the average default probability being positive but only marginally so.

Hence, in some cases, lowering interest rates may well stimulate the economy but also contribute to an increase of systemic risk. In our model, this happens through a

[14] Note that there is no truly dynamic aspect in the partial equilibrium model and it can be seen as a sequence of static problems. The general equilibrium model of section 4 will feature a fully dynamic household problem which affects the banking problem via demand for deposits.

change in the composition of intermediaries. Less risk-taking intermediaries exit levered markets and decrease their asset holdings as they are priced out by more risk-taking institutions due to decreasing returns to capital. The latter use low interest rates to increase their leverage significantly. Given that risk-shifting is larger in riskier intermediaries, this also generates more risk-taking on aggregate. But these effects happen only for low levels of interest rates. At higher levels, there is no such trade-off between monetary policy and financial stability. Our framework, appropriately enriched, should ultimately help us quantify the importance of the risk-taking channel of monetary policy.

Even in the absence of monetary policy, these effects have implications for the cyclicality of leverage, systemic risk and aggregate risk-shifting. The cyclicality of the savings behaviour and its effect on equilibrium deposit prices will lead to cyclical movements in leverage and investment. In general equilibrium, we will look at how shocks to productivity and intermediary default propagate in this model.

4 General Equilibrium

In this section, we solve the model in general equilibrium by joining the household and intermediary problems. The objective of this section is to show that the financial sector equilibrium can be easily integrated in a standard general equilibrium framework, with monetary policy and productivity shocks, as well as costly default.

4.1 Monetary policy as a change in funding cost

In this section we allow intermediaries to fund themselves through wholesale funding l_{it}. We assume that the monetary authority can control the price of wholesale funding relative to deposits, by providing funds at a spread γ_t from deposits.[15]. The price of wholesale funding is q_t^L and we denote the price of deposits as q_t^D. We have that:

$$q_t^L = q_t^D(1 + \gamma_t) \tag{25}$$

Monetary policy is exogenous, akin to a funding subsidy γ_t which follows a simple AR(1) process in logs.

$$\log \gamma_t = (1 - \rho^\gamma)\mu^\gamma + \rho^\gamma \log \gamma_{t-1} + \varepsilon_t^\gamma \tag{26}$$

$$\varepsilon_t^\gamma \sim N(0, \sigma_\gamma) \tag{27}$$

[15] The monetary authority is assumed to be a deep-pocketed institution which can always fund wholesale funding. Like deposits, wholesale funds are always repayed (by bailout if necessary). To avoid dealing with the monetary authority's internal asset management, we assume the cost of fund is a deadweight loss (or gain).

where μ^γ is the central bank target subsidy, ρ^γ the subsidy's persistence and ε^γ are monetary policy shocks with σ_γ standard deviation.

If the central bank were to provide unlimited funds to intermediaries at this rate, they would leverage using only wholesale funding. We assume that wholesale funding is given in a fixed proportion λ of other liabilites, which in this case are simply deposits. Total wholesale funding for intermediary i is then:

$$l_{it} = \lambda d_{it} \tag{28}$$

The balance sheet of an intermediary i is then:

Assets	Liabilities
k_{it}	ω
	$q_t^D d_{it}$
	$q_t^L l_{it}$

Given our assumptions, we can then define q_t^F as the total cost of a unit of funding and f_{it} as total external funds of bank i.

$$q_t^F = \frac{1 + \lambda(1 + \gamma_t)}{1 + \lambda} q_t^D \tag{29}$$

$$f_{it} = (1 + \lambda) d_{it} \tag{30}$$

We can then write the balance sheet as:

Assets	Liabilities
k_{it}	ω
	$q_t^F f_{it}$

We obtain the same banking problem as before, replacing deposits by total funds f_{it} and the deposit price by the unit cost of funds q_t^F. Since γ_t is an exogenous variable, we can map f_{it} and q_t^F easily to deposits d_{it} and their price q_t^D. By moving γ_t the central bank will be able to change q_t^F as long as changes in equilibrium q_t^D do not offset perfectly the changes in the spread on the total cost of funding.

4.2 Solving the dynamic model

The financial sector equilibrium can be seen as a sequence of static problems given funding costs q_t^F. We can then solve for the aggregate capital stock K and cutoff α_t^L as a function of q_t^F and expected productivity Z^e.

$$K = K^*(q^F, Z^e) \tag{31}$$

$$\alpha^L = \alpha^{L,*}(q^F, Z^e) \tag{32}$$

By integrating balance sheet equations, we obtain an expression for total funds F_t and deposit supply D_t:

$$q_t^F F_t = \int_{\alpha_t^L}^{\overline{\alpha}} k_{it}^L \; dG(\alpha^i) - [1 - G(\alpha_t^L)]\omega \tag{33}$$

$$D_t = \int_{\alpha_t^L}^{\overline{\alpha}} d_{it}^L \; dG(\alpha^i) = \frac{F_t}{1+\lambda} \tag{34}$$

where $F_t = \int f_{it} \; dG(\alpha^i)$ are total liabilities held by *active* intermediaries and D_t is aggregate deposit demand. Market clearing in the deposit market also requires supply and demand to be equal.

$$D_t^H = D_t \tag{35}$$

The goods market clearing also requires that output is used in consumption of households and intermediaries, investment and the accumulation of storage. The investment good is the consumption good and there we allow for disinvestment.

$$S_{t-1}^H + S_{t-1}^I + Y_t = C_t^H + C_t^I + S_t^H + S_t^I + I_t + T_t \tag{36}$$

where $C_t^I = \int c_t^i \; dG(\alpha^i)$ and $T_t = \int t_t^i \; dG(\alpha^i)$. Note that taxes here are equal to the capital injections, which require real resources. S_t^H are the holdings of storage held by households and $S_t^I = \int s_t^i \; dG(\alpha^i)$ are aggregate storage holdings held by financial intermediaries at t.

To find an equilibrium, we need to have the deposit price which, conditional on exogenous variables and the financial sector equilibrium, is consistent with the household problem. We proceed by iterating on q_t^D, imposing the financial market equilibrium results. For a given deposit price q_t^D, we can find the law of motion for household wealth and consumption and use the Euler equation errors to update the deposit price. A more detailed explanation of the algorithm used for our global solution method can be seen in Appendix A.

To define formally the equilibrium, let $\mathcal{S} = \{D_{t-1}, S_{t-1}^H, K_{t-1}, Z_{t-1}, \gamma_{t-1}, \varepsilon_t^z, \varepsilon_t^\gamma\}_{t=0}^\infty$ be the vector of state variables and shocks. Given a sequence of prices $\{q_t^D\}_{t=0}^\infty$ and financial market rules $K^*(\mathcal{S}), \alpha^{L,*}(\mathcal{S})$, define the optimal decisions of the representative household as $C^H(\mathcal{S}), D^H(\mathcal{S}), S^H(\mathcal{S})$. We can then define the equilibrium as follows.

Definition 1 An equilibrium is a sequence of prices $\{q_t\}_{t=0}^\infty$, and policy rules $C^H(\mathcal{S}), D^H(\mathcal{S}), S^H(\mathcal{S}), K^*(\mathcal{S}), \alpha^{L,*}(\mathcal{S})$, such that:

- $C(\mathcal{S}), D^H(\mathcal{S}), S^H(\mathcal{S}), K^*(\mathcal{S}), \alpha_t^{L,*}(\mathcal{S})$ are optimal given $\{q_t\}_{t=0}^\infty$
- Asset and consumption markets clear at every period t

4.3 Calibration

To solve the model numerically, we need to choose the period utility function, the distribution of the Value-at-Risk probabilities of intermediaries and calibrate the remaining parameters. Given the interaction between extensive and intensive margin effects, the mass of intermediaries in a given section of the distribution could have an important role in determining which of the two effects dominates. To highlight that the results described are not a consequence of this distribution, we assume that $G(\alpha^i)$ is uniform between $[0, \overline{\alpha}]$. For the utility function, we assume a standard CRRA representation.

$$u(C) = \frac{C^{1-\psi} - 1}{1 - \psi} \tag{37}$$

Table 1: Calibration of selected parameters

Parameter	Value	Description
ψ	4	Risk aversion parameter
β	0.95	Subjective discount factor
ρ^z	0.9	AR(1) parameter for TFP
σ_z	0.028	Standard deviation of TFP shock
μ^γ	0.02	Target spread over deposit rates
ρ^γ	0.24	Spread persistence
σ_γ	0.01	Standard deviation of spread
$\frac{\lambda}{1+\lambda}$	0.3	Central Bank funding percentage
θ	0.35	Capital share of output
δ	0.1	Depreciation rate
ω	0.5	Equity of intermediaries
$\overline{\alpha}$	0.1	Upper bound of distribution $G(\alpha^i)$

The calibration can be seen in Table (1). For the utility function parameters, risk aversion ψ and the subjective discount factor β, we chose standard values from the literature. Similarly for θ, the capital share of output, and for δ the depreciation rate of the capital stock.

$\overline{\alpha}$ is the probability of default of the riskiest intermediary in activity. Bali, Brown and Caglayan (2014) report that the median lifespan of a hedge fund is slightly less than 5 years, which would imply a value of approximately 0.2. Given our specification of a uniform distribution and the fact that equity size is fixed, we use a more conservative (even if still very large) value of 0.1. This implies an average lifespan of 10 years for the most risky of financial intermediaries and 20 years for the median intermediary. ω was chosen so that the average leverage is close to 10. [16]

Ideally, one would back out from the data the distribution of leverage and map it into $G(\alpha)$. We could also infer a distribution for intermediate-specific ω from the size of each type of participant. We leave that for future work and focus for now on exploring the effect of the change in the marginal intermediary, when intermediaries are identical in all respect except their Value-at-Risk constraint. This helps to isolate the effects of having different Value-at-Risk parameters, which is the core of the model.

4.4 Monetary policy shocks

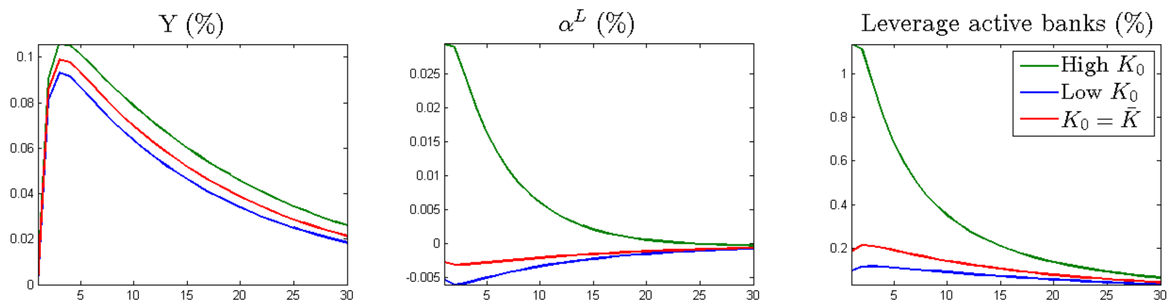

Figure 4: *Monetary policy shock of 100 basis points to* γ_t

In Figure (4) we see the impact of a 100 basis points monetary policy shock in 3 different scenarios to illustrate the non-linear effects of monetary policy on systemic risk. Scenario 1 features a low initial capital stock (corresponding to high equilibrium levels of the interest rate), where there is no trade-off between monetary policy and financial stability and scenario 2 is for a larger capital stock (corresponding to a low level of equilibrium interest rate) where we are in the trade-off zone. Scenario 3 is at the risky steady-state[17]. As in Coeurdacier et al. (2011) we define the risky steady-state as

[16] The value of $\overline{\alpha}$, the shape of the distribution and also ω will all contribute to determine the financial sector reaction to changes in deposit rates. For that reason, we also conducted some comparative statics on both $\overline{\alpha}$ and ω to see how the model changes with those parameter calibrations. There is very little effect on the first moments of real variables such as output and consumption, although there are important changes on equilibrium leverage as we change ω and on the risk premium as we change $\overline{\alpha}$.

[17] These three scenarios were chosen to illustrate the parallel with the partial equilibrium setting, since the solution of the model is such that there is, ceteris paribus, a negative correlation between the

the steady-state in which there are no shocks but economic agents take into account the full stochastic structure of the model when they optimize (unlike in the deterministic steady-state where they expect no shocks). Very interestingly, we can easily relate the general equilibrium results to the partial equilibrium intuitions developed above. In the case of a low initial capital stock (associated with a high equilibrium funding rate), a positive monetary policy shock expands output, increases aggregate leverage (as the capital stock goes up and equity is fixed) and at the same time it decreases systemic risk, thanks to less risk-taking intermediaries levering more. We are in the "no trade-off zone of monetary policy" where a decrease in the interest rate increases investment and financial stability. In the case of a high initial capital stock (associated to a low funding cost for intermediaries), an expansionary shock has a larger positive effect on output and leverage but this time, risk averse intermediaries at the margin choose not to lever, reducing their balance sheet size significantly. Less risk averse intermediaries leverage a lot and financial stability is affected negatively. We are in the "trade-off zone of monetary policy" where there is a conflict between stimulus and financial stability. This is a very different trade-off from the traditional Phillips curve which has been the benchmark model driving monetary policy analysis for many years. Aggregate economic variables behave smoothly but the underlying change in financial structure supporting these macroeconomic outcomes can be dramatic depending on the level of the interest rate.

5 Empirical evidence on the cross-section of intermediaries balance sheets

.

Our model, unlike the previous literature which did not usually feature intermediaries heterogeneity, has interesting implications for the cross-section of intermediary balance sheets, namely regarding leverage and how its distribution varies over the cycle.

First, aggregate leverage is not only monotonically decreasing with the interest rate, its derivative is also monotonically increasing. So when interest rates are low, further reductions lead to larger increases in leverage than when they are high. This is because the sensitivity of leverage to the cost of funding is larger for intermediaries who are in the upper range of the risk-taking distribution (conditional on remaining active). So the more concentrated is capital in this upper range, the more sensitive will aggregate leverage be to interest rate changes.

capital stock and the deposit rates as can be seen in figure (2)

We used banks balance sheet data to compute leverage at the bank level. Leverage is defined as the ratio of assets over equity at book value. In Figure (10) we show the time series of leverage weighted by bank assets (a very similar picture can be obtained if one uses equity weights). We separate the top of the distribution (75th percentile) from the bottom (25th percentile). Before 1984-85 there seems to be no noticeable correlation. After that the correlation is striking, with a clear dichotomy between the two parts of the distribution. Ihe more leveraged banks increase their leverage sizably as the interest rate goes down. In particular, there are two leverage spikes corresponding to very low levels of the interest rate: during the pre-crisis period and after 2009. In contrast, after an initial moderate increase in leverage (between 1984 and 1992, following a decline in the Fed Funds rate), the less leveraged banks deleverage massively after 1992 as the interest rate falls further down and keep a constant low leverage after that. We interpret this fact as the less risk-taking intermediaries effectively exiting the risky leveraged business model as they are priced out by the most risk-taking ones.

It would be interesting (but beyond the scope of this paper) to determine whether the change in correlation between leverage and the Effective Fed Funds Rate is due to the wave of the deregulation of the 1980s (in the US the Depository Institutions Deregulation and Monetary Control Act of 1980 and the GarnSt. Germain Depository Institutions Act of 1982 eroded the distinctions between banks and other financial institutions).

Second, a very distinct implication of the model is that low levels of the interest rate are associated with an increased skewness of leverage: risk gets concentrated in the (endogenously) larger, more risk-taking players. As with aggregate leverage, when rates are low, skewness is also more sensitive to interest rate movements. In Figure (5), we show the shape of cross-sectional skewness as a function of q for three different levels of productivity. It is also apparent that the direct impact of productivity on skewness, although positive, seems second-order relative to the impact of interest rates.[18]

We use banks balance sheet data to compute the time series of the skewness of leverage. In Figure (11), we present three time series of skewness: unweigted, weighted by equity and weighted by assets in parallel with the movements of the effective fed funds rate. Again, there is no noticeable correlation before 1984-85 but after that the correlation is again remarkable. After 1984, lower rates are strongly correlated with increased positive skewness. These results are striking and very encouraging for the mechanism of our model. We are not aware of any paper studying the distribution and

[18]Although in general equilibrium productivity will also affect skewness indirectly via its impact on deposit prices

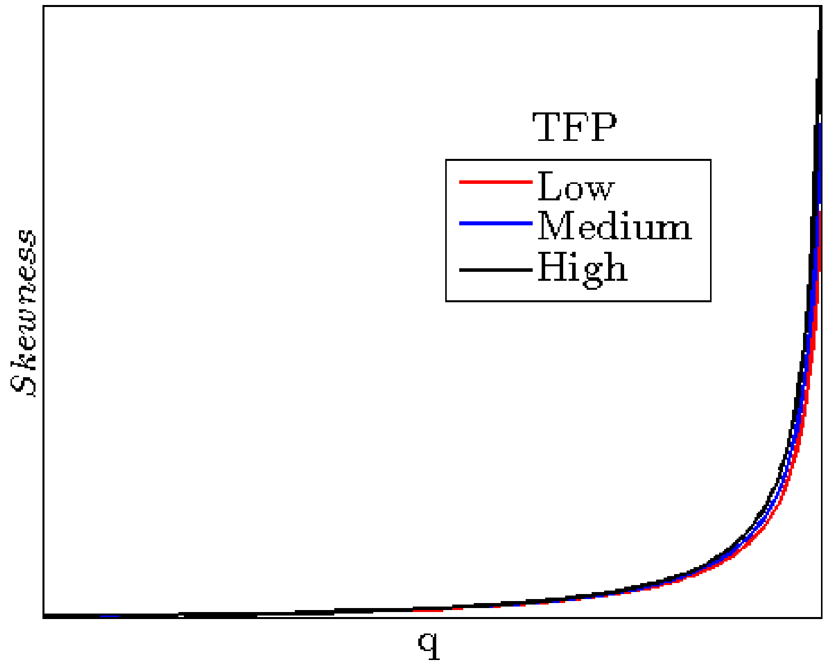

Figure 5: *Skewness as a function of deposit prices q*

skewness of leverage and linking it to monetary policy.

The model also implies that in the cross-section (endogenously) larger more leveraged intermediaries make higher profits in good states of the world but are more exposed to aggregate risk. Accordingly we analyse the returns of financial intermediaries in the run up to the crisis and look at its correlation with leverage and with the exposure to aggregate risk (measured by the world market beta). Figure (6) shows a positive correlation between pre-crisis betas and returns. We also find a positive correlation between returns and leverage, confirming the results of Miranda-Agrippino and Rey (2015).

6 Costly intermediary default

In this section we relax the assumption of costless intermediary default. As in the previous section, levered intermediaries active in risky financial markets can potentially default on depositors if the realisation of the productivity shock is low enough. This requires intervention by the government to pay deposit insurance, which might be less

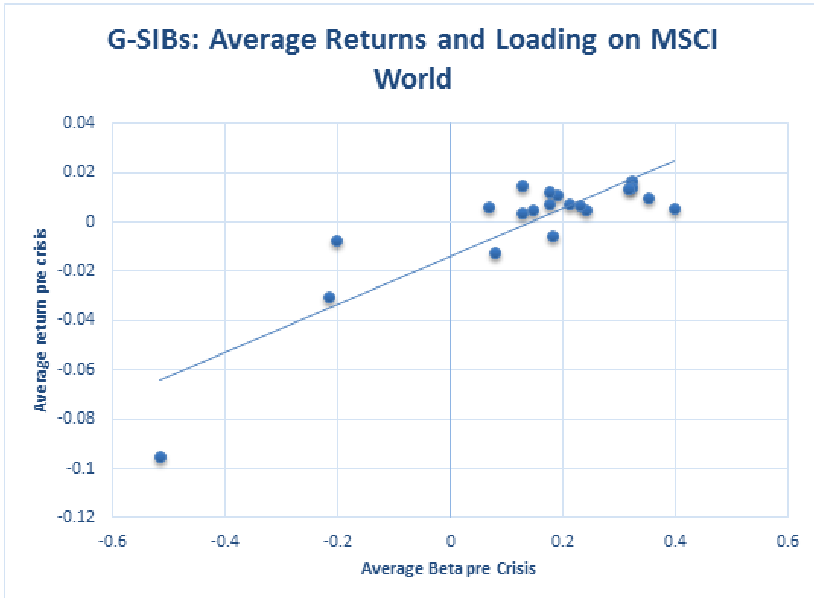

Figure 6: *Market beta and pre-crisis returns for Global Systemically Important Banks (G-SIBs)*

benign than previously assumed.

We parameterize the cost of intermediary bailouts by assuming that the return on capital held by defaulting intermediaries suffers a proportional loss $\overline{\Delta}$ relative to capital held by non-defaulting intermediaries. This disruption can affect financial markets in the following periods by creating an efficiency loss Δ_t which is proportional to the mass of capital held by defaulting banks μ_t^d.[19]

So the loss of productivity is intermediary-specific during default (it affects only the defauting intermediaries, not the others), but it can affect the whole sector moving forward. We call this the *crisis* state. We model the persistence of the crisis state through a Poisson process, with a constant probability p of exiting the crisis at each period. Depending on the process, variable ξ_t takes the value of one if the crisis carries on to the next period or zero if it does not. Our specification nests both the case of costless default ($\overline{\Delta} = 0$) and the case where there is no disruption of financial markets in subsequent periods ($p = 1$). We then have:

[19]For example, if defaulting intermediares held 3% of total capital during default at $t-1$, then if the crisis persists $\Delta_t = 0.03\overline{\Delta}$.

$$\mu_t^d = \frac{\int k_{it} \ \mathbb{1}_{(\pi^i < \omega)} \ dG(\alpha^i)}{K_t} \tag{38}$$

$$\Delta_t = \xi_{t-1} \max(\mu_{t-1}^d \ \overline{\Delta}, \Delta_{t-1}) \tag{39}$$

$$\tag{40}$$

where the indicator function takes the value of 1 if intermediary i is in default or 0 if not. If there are also defaults during a crisis state, then the max operator ensures that the largest penalty applies going forward. Productivity for all financial intermediaries is scaled down (whenever the economy is in crisis) by a factor proportional to the percentage of total capital held defaulting banks. ξ_{t-1} is known to agents when they make their investment decisions at period $t-1$, so the uncertainty on the returns on their capital investment is only on the realization of the exogenous productivity process[20]. This timing assumption allows us to keep tractability as the main difference in the financial sector block is that now $Z_{t+1}^e = (1-\Delta_t) Z_t^{\rho^Z}$. Since both Δ_t and Z_t are state variables, then we can still solve for the financial sector equilibrium as before.

This set up is tractable and allows us to parameterize crises of different severity and length. Borio et al. (2016) present empirical evidence showing that there can be substantial and long lasting productivity drops after financial crises. We calibrate $p = 0.5$ which implies an average crisis length of 2 years and $\overline{\Delta} = 0.05$ implying a maximal efficiency loss of 5% .

6.1 Productivity shocks and financial crises

In this section we study the impact of a financial crisis on the path of the economy, following a large productivity shock. Figure (7) shows the impact of a large productivity shock in 3 possible scenarios.

Scenario 1 is when the economy at the risky steady-state is hit at period t by the largest possible shock that does not trigger defaults. Scenario 2 and 3 are when the economy is hit with the smallest shock such that all *levered* intermediaries default. The difference between scenarios 2 and 3 is in the length of the crisis. Scenario 2 is the "lucky" scenario, where the crisis does not carry on to the next periods: $\xi_t = 0$. Scenario 3 is the "unlucky" scenario, where the crisis carries on for an additional 4 periods: $\xi_s = 1$ for $s = t$ to $t+3$. Not surprisingly, when crisis hits there is a large decline in

[20]There is still uncertainty on asset returns if the intermediary defaults but this penalty is not considered in the intermediary problem due to limited liability truncating the profit functions at zero in those states.

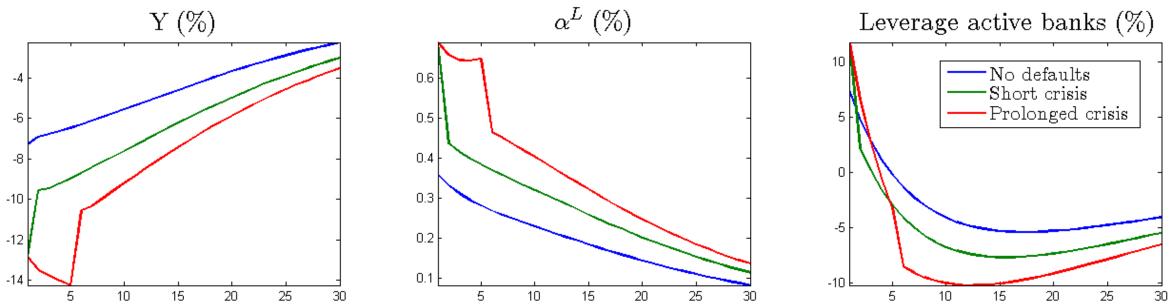

Figure 7: *Large shock to exogenous productivity*

output. As productivity is low, only the most risk-taking intermediaries can operate. The average leverage of active intermediaries first shoots up but then decreases and falls below the pre-crisis state as more interimediaries find it worthwhile to enter the risky business model again when productivity improves. Note that this initial rise is a pure composition effect as total sector leverage falls[21]. The increase in the average leverage of active banks is then purely due to the exit of the least levered active intermediaries from the risky business model leaving only the most risk-taking ones active initially.

The length of the crisis also has very interesting dynamic effects. Given that households expect to exit the crisis state with probability p, then when exit fails to materialize in Scenario 3 they are effectively running down their wealth. The deposit rate grows as it becomes more costly for the household to save and fund bank leverage. When eventually the economy exits the crisis state, household wealth is low and demand for leverage rises, leading to a jump in deposit rates to again compensate households for decreased consumption today. The economy then exits the crisis with a risk-premium above the pre-crisis levels, due to high cost of funding. This effect is also present with a short crisis, but is particularly stark for the longer crisis.

7 Conclusion

This paper develops a novel framework for modeling a financial sector with heterogeneous financial intermediaries. The heterogeneity in the Value-at-Risk constraints generates not only endogeneous entry and exit in risky capital markets, but also time variation in leverage, risk-shifting and systemic risk.

[21] See Figure 14

The interaction between the intensive and the extensive margins of investment generates a rich set of non-linear dynamics where the level of interest rates plays a key role. When interest rates are high, a monetary expansion (defined here as a decrease in the cost of funding for intermediaries) increases both the intensive margin (the amount of leverage) and the extensive margin (which intermediaries leverage up). The intensive margin grows because active intermediaries are able to lever more and the fall in the cost of funding leads to increased participation by less risk-taking institutions which enter levered markets. The monetary authority is then able to stimulate the economy, while at the same time decreasing systemic risk.

However, when interest rates are already initially low, a further reduction can lead to large increases in leverage by the most risk-taking institutions, pricing out previously active intermediaries despite the fall in the cost of funding. As before, the intensive margin grows but there is a fall in the extensive margin as intermediaries at the margin exit levered markets. Importantly, the intermediaries who stop levering and decrease their balance sheet size have lower probabilities of default than those that remain levered, leading to an increase in systemic risk.

Limited liability plays a crucial role in these dynamics by creating an option value of default. This induces risk-shifting by financial intermediaries and increases willingness to pay for risky assets. Voluntary entry and exit will then happen at the lower range of risk-shifting from active intermediaries, generating a a potential increase in systemic risk. In the model there is no idiosyncratic risk, so this effect on systemic risk is happening because of the shift in business model of intermediaries and not because of a fall in the number of institutions in the market.

Because our framework has heterogeneity at its heart, it allows us to make us of cross-sectional data on intermediary balance sheets. For example, we derive novel implications linking the times series of the skewness of leverage and monetary policy. These implications are borne out in the data, particularly since the mid-80s after which there is a striking correlation.

Our financial block is easy to embed in a more standard general equilibrium framework, as the rich dynamics that arise from the composition of active financial intermediares can be described simply by the dynamics of the aggregate capital stock K_t and the cutoff α_t^L. We plan to extend our model to environments with sticky prices and a more complex portfolio choice on the bank side. We also plan to apply it to explain the dynamics of the real estate market, using detailed data. We will as well use it to study boom and bust cycles in emerging markets as well as the endogenous dynamics of the VIX.

The model can also be calibrated to fit a more realistic distribution of financial intermediaries, as one could in practice back out the distribution of α^i from leverage data and map it to the ergodic distribution of leverage in the model. Given the numerical integration approach, it is also possible to extend the model to have a distribution of intermediary-specific equity ω^i. That said, allowing for time variation in equity would require the introduction of an additional state-variable in the financial sector problem which would make the solution more computationally intensive.[22] We leave these issues for future research.

[22] And having at the same time time-varying and intermediary-specific equity could require an infinitely dimensional state-space without additional assumptions.

Figures

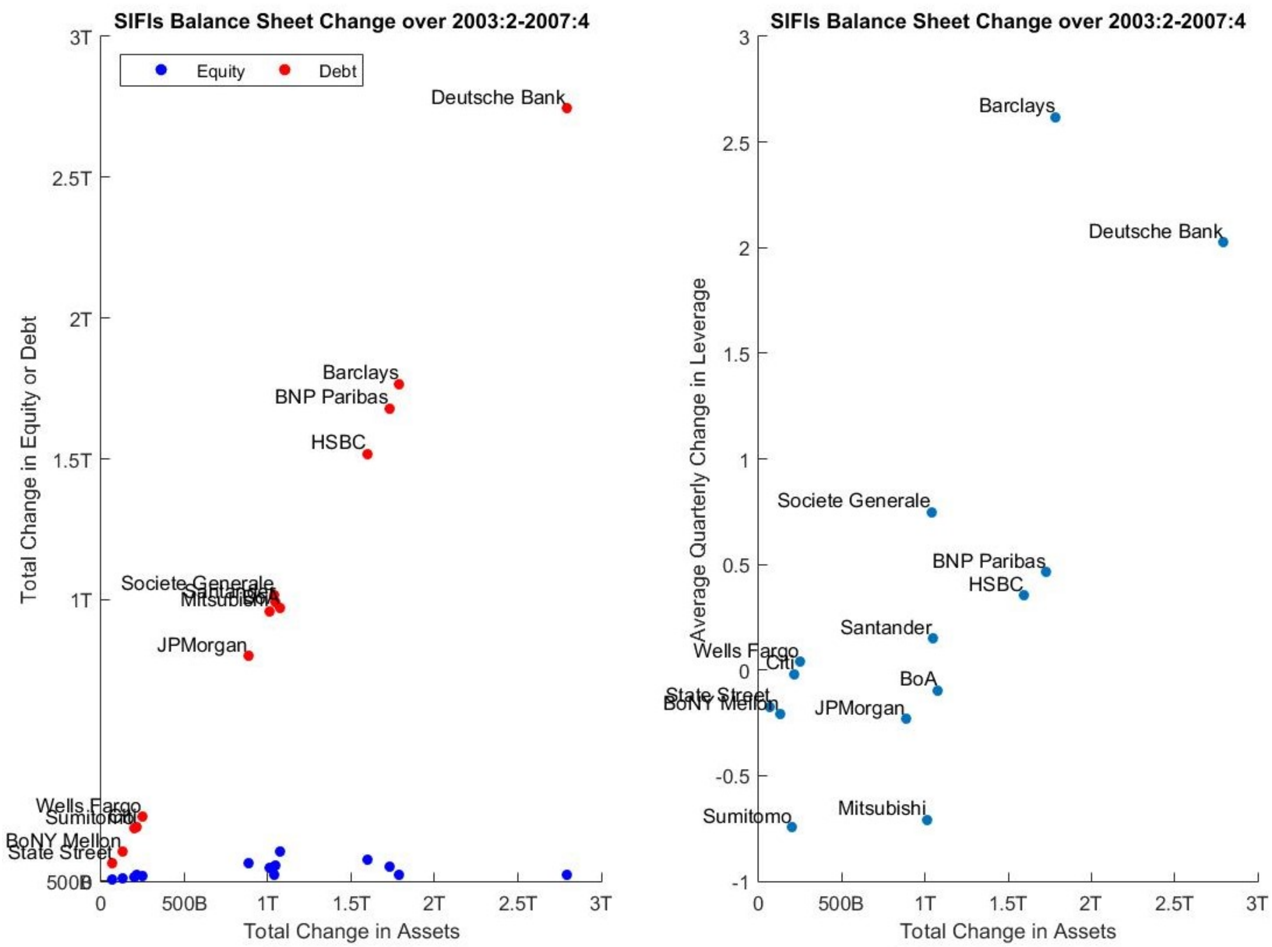

Figure 8: *SIFIs Balance sheet changes in the crisis run up: total change in size versus change in equity or debt.*

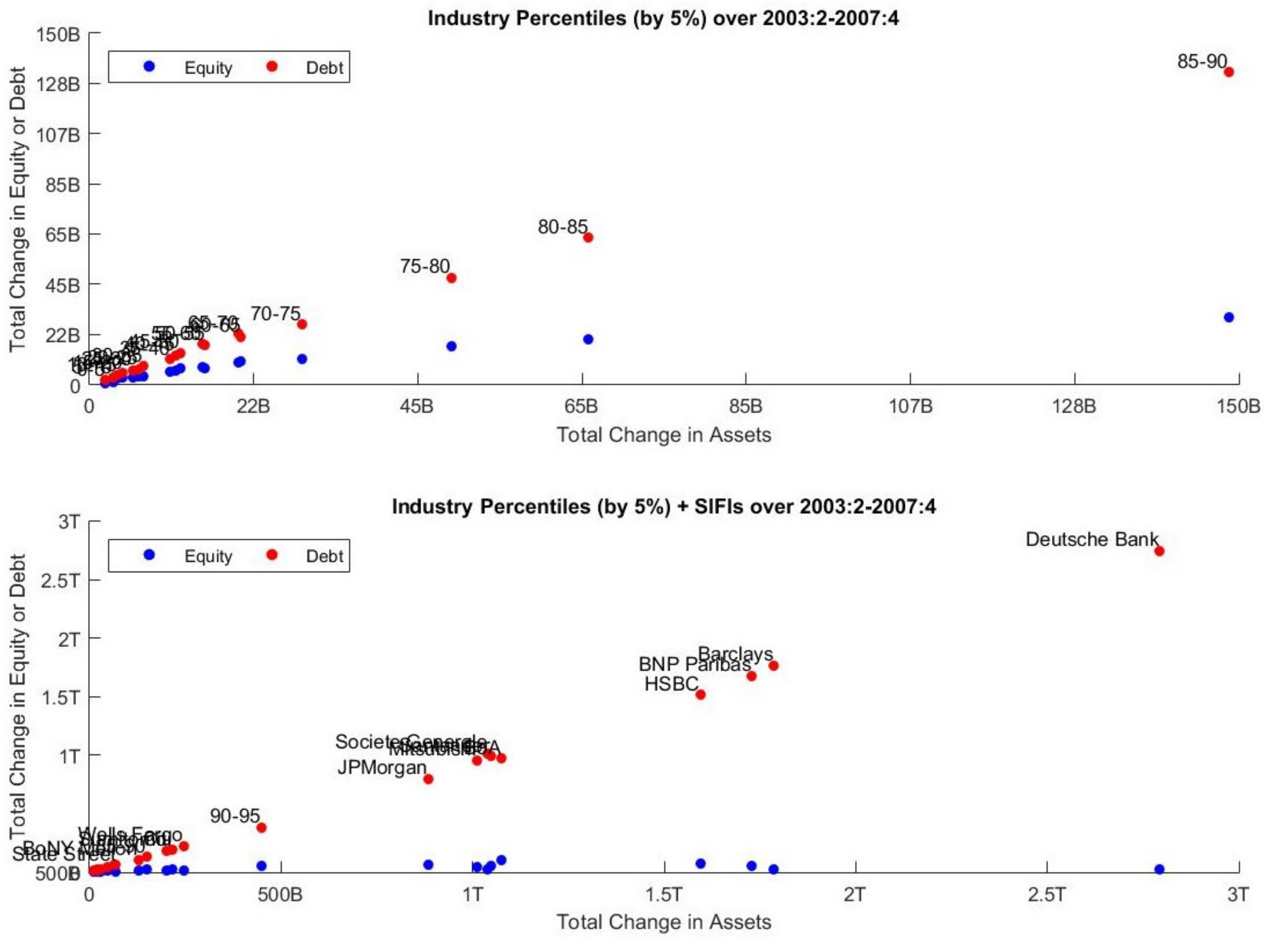

Figure 9: *Industry and SIFIs Balance sheet changes in the crisis run up: total change in size versus change in equity or debt.*

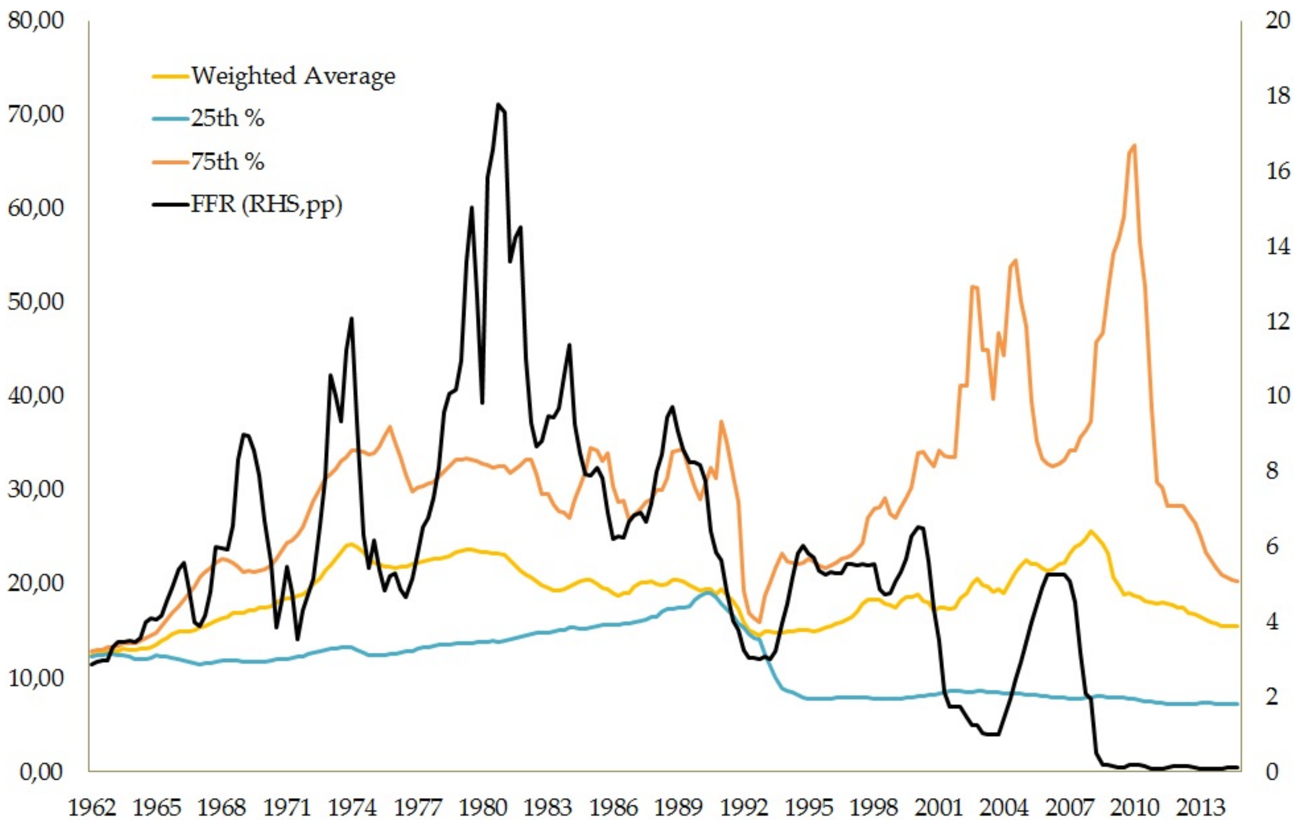

Figure 10: *Time series of the leverage of banks and the Effective Fed Funds Rate. Leverage is weighted by assets. The 25 and 75 percentiles of banks are shown.*

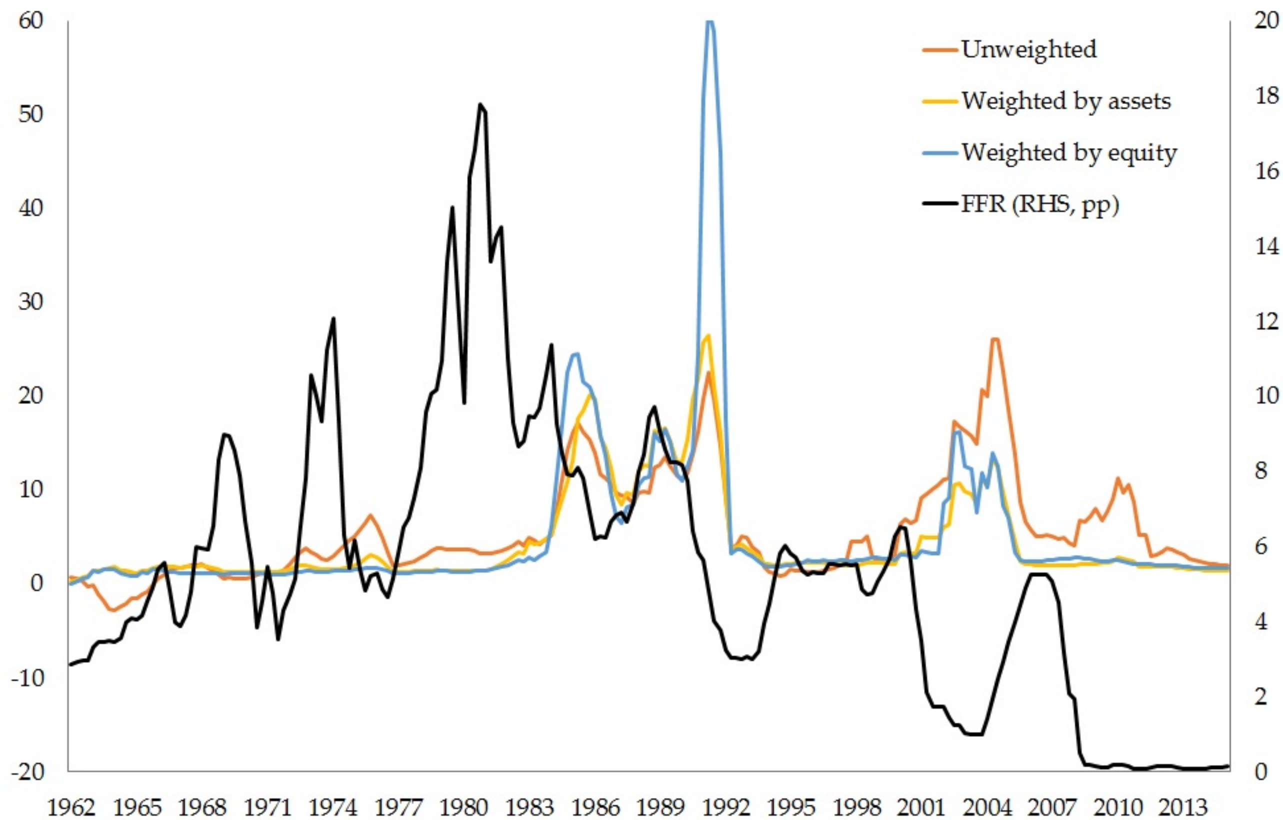

Figure 11: *Time series of the skewness of leverage of banks and the Effective Fed Funds Rate. Skewness is left unweighted or weighted by assets or by equity.*

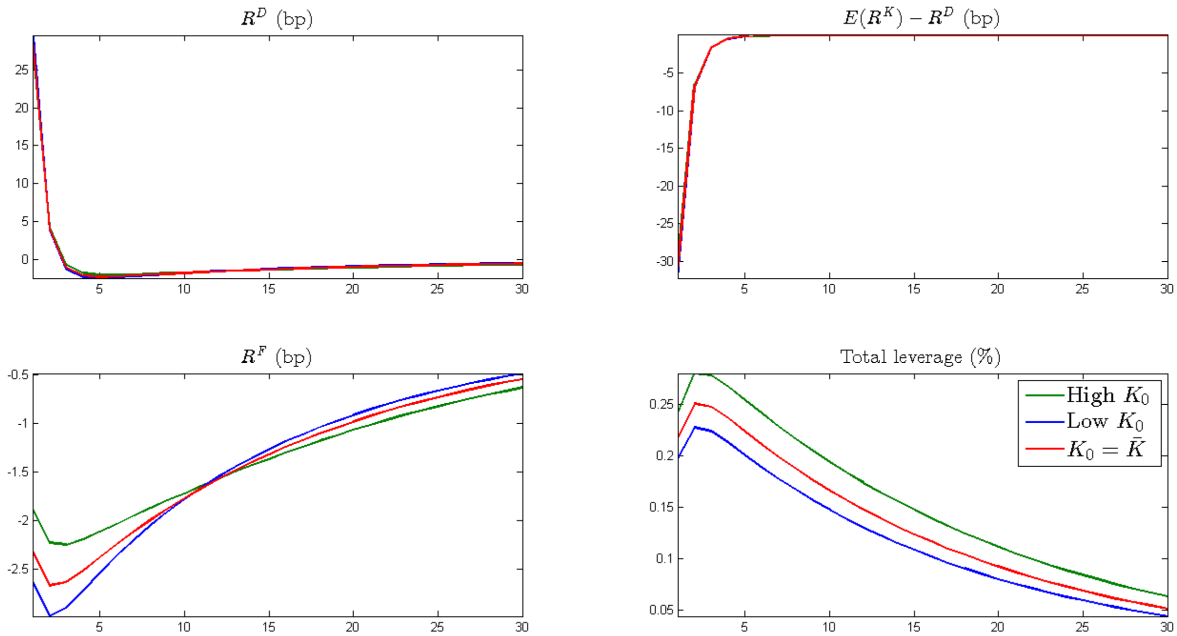

Figure 12: *Monetary policy shock of 100 basis points to* γ_t *- Financial Variables: Deposit rate, spread between the expected retruns to capital and the deposit rate, funding rate and total leverage.*

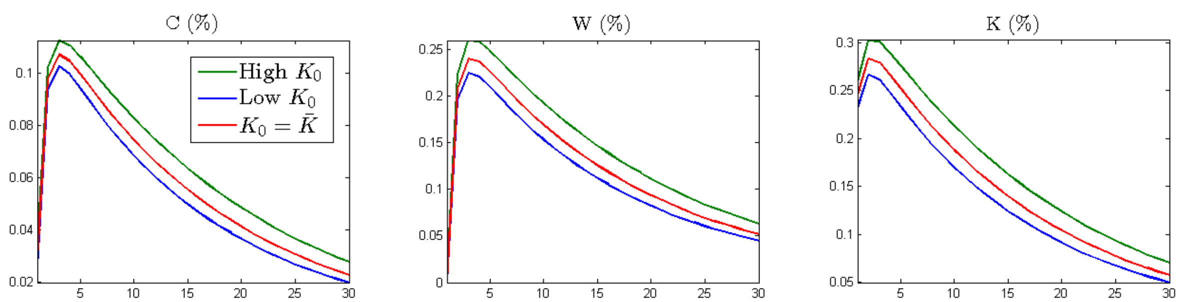

Figure 13: *Monetary policy shock of 100 basis points to* γ_t *- Real variables: consumption, wage income, capital stock.*

Productivity shock

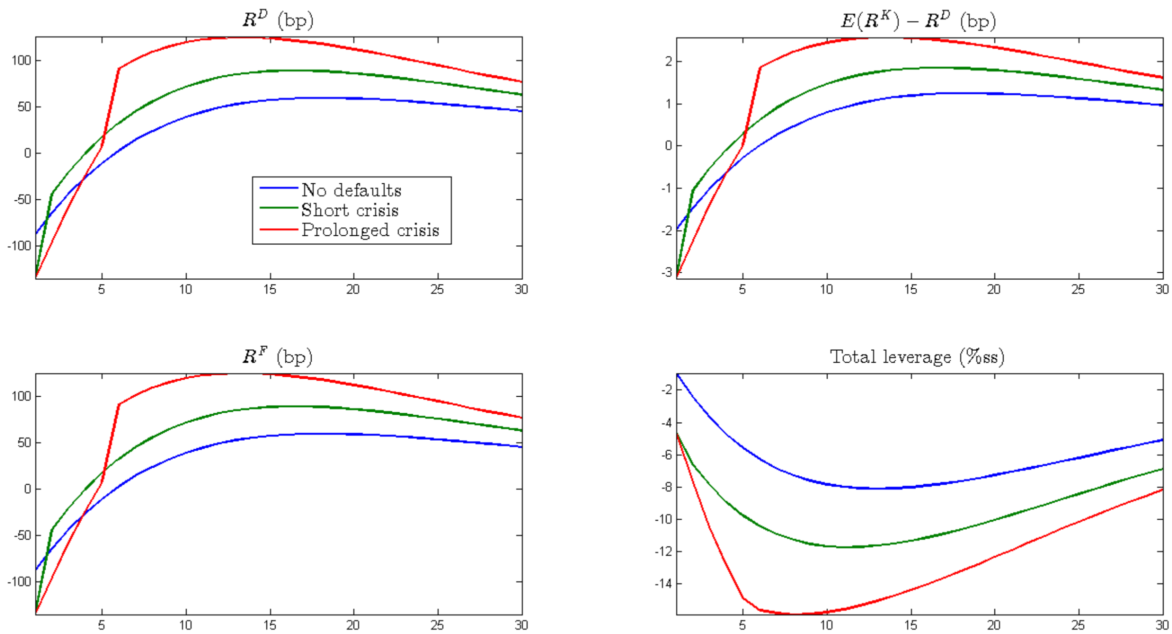

Figure 14: *Large shock to exogenous productivity - Financial Variables: Deposit rate, spread between the expected retruns to capital and the deposit rate, funding rate and total leverage.*

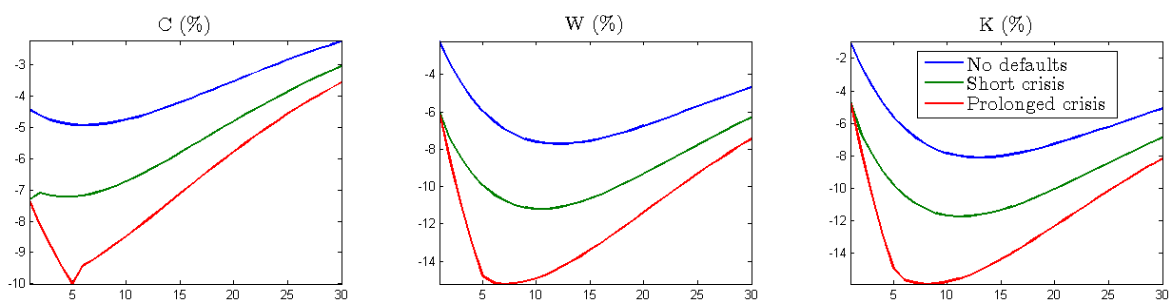

Figure 15: *Large shock to exogenous productivity - Real variables: consumption, wage income, capital stock.*

Appendix A. Numerical solution method

The solution method is composed of two main blocks. The first block solves the partial equilibrium problem for a grid of points for variables q^f and Z^e. We discretize the state space using 100 nodes for Z^e and 200 for q^f. Given funding costs q^f and expected productivity Z^e we can solve jointly for equations (21) and (23), plugging in equation (17) in the latter. This gives us policy functions $K^*(q, Z^e)$ and $\alpha^{L,*}(q^f, Z^e)$.

The second block is the recursive one. First we define the household savings problem as a function of disposable wealth Ω_t, productivity $\tilde{Z}_t$, efficiency adjustment Δ_t and monetary policy γ_t.

$$\Omega_t = (1-\theta)Y_t - T_t + D^H_{t-1} + S^H_{t-1}$$

The procedure entails the following steps

1. Discretize the state space $\mathcal{S}$ for the variables $(\Omega, Z, \Delta, \gamma)$. The process for Z and γ are approximated using a Tauchen and Hussey (1991) quadrature procedure with 11 and 5 nodes respectively. The state space for the variable Ω is discretized using 500 nodes and we use 10 for Δ.

2. Iterate on prices q^D and policy function $C^*(\mathcal{S})$ starting with an initial guess $q^d(\mathcal{S})$ for deposit prices and $C^*(\mathcal{S})$. For every point $\mathcal{S}_j \in \mathcal{S}$:

   (a) Using the state vector and q^d_j, calculate q^f_j and Z^e_j.

   (b) Solve for (K_j, α^L_j) using $K^*(q^f_j, Z^e_j)$ and $\alpha^{L,*}(q^f_j, Z^e_j)$. Back out deposit supply D_j from the balance sheet equations.

   (c) Plug D_j in the budget constraint of the agent. Together with $C_j = C^*(\mathcal{S}_j)$ this pins down S^H_j.

   (d) Calculate expectations of $(\mathcal{S}'|\mathcal{S})$ and update deposit prices and policy functions using the optimality conditions and numerical integration.

   (e) Check for convergence. If $||(q'_j - q_j)|| + ||(C^*_j)' - C^*_j||$ is smaller than a threshold value stop. Else, go back to (a) and repeat.

To numerically integrate intermediary capital into aggregate capital, Gauss-Legendre quadrature using 51 points is used. To calculate expectations of future net disposable wealth, we also need to calculate taxes conditional on future shocks. For a given productivity draw $Z'|Z_j$ we identify the threshold intermediary for which no bailout is needed: $(R^K k_i - d_i) = \omega$. We can then calculate the amount T_t of taxes required by numerical integration.

Appendix B. Proofs

Theorem 7.1 *When $\mathbb{E}[R^K_{t+1}] > 1$, intermediary i will either lever up to its Value-at-Risk constraint: $d_{it} = \overline{d}^i_t$, or not raise deposits at all : $d_{it} = 0$.*

The Value-at-Risk constraint bounds the maximum level of leverage of intermediary i, therefore $d_{it} \in [0, \overline{d}^i_t]$. The profits of intermediary i as a function of deposits are:

$$\pi^i_t(d_{it}) = \int_{\varepsilon^i_t(d_{it})}^{\infty} \left[R^K_{t+1}(\omega + d^i_t) - R^D_t d^i_t\right] dF(\varepsilon) \tag{41}$$

where ε^i_t is the max of 0 (the lower bound of the support for ε) and the shock for which profits are zero)

$$\varepsilon^i_t = \max\left(0, \frac{\frac{R^D_t d^i_t}{\omega + d^i_t} - 1 + \delta}{\theta Z^{\rho^Z} K^{\theta-1}_t}\right) \tag{42}$$

Taking derivatives:

$$\frac{\partial \pi^i_t}{\partial d^i_t} = \int_{\varepsilon^i_t(d^i_t)}^{\infty} \left(R^K_{t+1}(\varepsilon) - R^D_t\right) dF(\varepsilon) - \pi^i_t(\varepsilon^i)\frac{\partial \varepsilon^i}{\partial d^i_t} \tag{43}$$

Lemma 7.1 *Given equations (41) and (42), then $\pi^i_t(\varepsilon^i_t)\frac{\partial \varepsilon^i}{\partial d^i_t} = 0$*

This is easy to check. For any $d_{it} \geq \frac{\omega(1-\delta)}{R^d_t - 1 + \delta}$, then $\pi^i_t(\varepsilon^i_t) = 0$. For $d^i_t < \frac{\omega(1-\delta)}{R^d_t - 1 + \delta}$, then $e^i = 0$ and $\frac{\partial \varepsilon^i}{\partial d^i_t} = 0$ due to the max operator.

We then have as first and second derivative:

$$\begin{aligned} \frac{\partial \pi^i_t}{\partial d_{it}} &= \int_{\varepsilon^i_t}^{\infty} \left(R^K_{t+1}(\varepsilon) - R^D_t\right) dF(\varepsilon) \\ \frac{\partial^2 \pi^i_t}{\partial d^2_{i,t}} &= -\left[R^K_{t+1}(\varepsilon(d_{it})) - R^D_t\right] \frac{\partial \varepsilon^i_t}{\partial d_{it}} \end{aligned} \tag{44}$$

Given the monotonicity of $R^K_{t+1}(\varepsilon)$, then $\forall \tilde{d}$ such that $\left.\frac{\partial \pi^i_t}{\partial d_{it}}\right|_{\tilde{d}} = 0$, then it follows that $R^K_{t+1}(\varepsilon(\tilde{d})) - R^D_t < 0$ or all elements in the integral are non-negative and it cannot be zero for finite $\tilde{d}$. Then $\left.\frac{\partial^2 \pi^i_t}{\partial d^2_{it}}\right|_{\tilde{d}} > 0$ and if $\tilde{d}$ exists then it is a minimum. We then have that the maximum must be at the bounds: $d_{it} = \arg\max\left(\pi_t(0), \pi^i_t(\overline{d}^i_t)\right)$

Appendix C: Data Description

Bank balance sheet data is from the Compustat Bank Fundamentals Quarterly database. Banks returns data is from CRSP. MSCI World Index data is from Bloomberg. The Effective Federal Funds Rate is from the Federal Reserve Economic Data. All data has been accessed on April 11, 2016.

The leverage ratio is defined as the ratio of total assets to total equity. Total assets and equity are the variables "atq" and "seqq" in Compustat, respectively, the latter being defined as described as Stockholders Equity Parent Quarterly. Alternatively one can use "ceqq" for total equity, described as Common/Ordinary Equity. Results are very similar. Total liabilities are defined as "lseq" minus "seqq" (total liabilities and equity minus Total equity). We drop negative equity and negative assets from the dataset.

For the leverage series, we compute both unweighted and weighted averages of the leverage ratio for each quarter. For the weighted average we use total assets or total equity as weights. We also compute the 25th and the 75th percentiles of both unweighted and weighted leverage, the former being just a special case of the latter where the weighting vector is a vector of ones. We perform 4-period MA filtering on the resulting series.

For the skewness of leverage, we compute the cross-sectional standard deviation and third moment of the leverage ratio for every period. And then compute the cross-sectional sample skewness using a simple approach laid out below.

$$m_t(3) = \frac{\sum_{i=1}^{N} (x_{it} - \bar{x}_t)^3}{N}$$

$$s_t = \sqrt{\frac{\sum_{i=1}^{N} (x_{it} - \bar{x}_t)^2}{N-1}}$$

$$S_t = \frac{m_t(3)}{(s_t)^3}$$

where x_{it} is the leverage ratio of bank i in period t, $\bar{x}_t$ is the period-specific cross-sectional mean of leverage, S_t is the sample cross-sectional skewness in period t, s_t is the period-specific sample cross-sectional variance and $m_t(3)$ the period-specific sample third central moment of the cross-section. We use this approach to the unweighted serie or weighted by either total assets or total equity.

Table 2: Descriptive statistics by year

Years	Observations		Total Assets			Total Equity			Leverage Ratio		
	Banks	Leverage	Mean	Median	St.Dev.	Mean	Median	St.Dev.	Mean	Median	St.Dev.
1962	45	6	2668.3	1313.7	2973.8	550.8	466.7	263.3	13.3	14.0	1.2
1963	47	31	2509.3	1268.4	2822.4	296.4	303.9	253.3	12.8	12.8	1.3
1964	49	42	2655.0	1359.8	3003.3	376.4	313.4	324.6	12.4	12.7	2.8
1965	59	68	2681.5	1386.7	3262.5	295.7	87.6	330.7	13.0	13.1	2.7
1966	90	194	2297.4	989.3	3372.4	155.3	58.5	238.7	14.0	13.9	2.9
1967	104	348	2300.1	1014.2	3523.3	154.3	70.9	210.2	14.3	13.9	3.6
1968	109	370	2544.8	1124.8	3876.6	157.9	74.2	214.5	15.2	14.8	4.1
1969	111	385	2819.0	1197.0	4297.1	170.3	80.3	222.3	15.2	14.8	3.5
1970	129	457	2714.7	1107.4	4536.0	160.5	78.1	218.6	15.2	14.8	3.5
1971	141	502	2947.7	1279.2	4945.9	166.4	82.4	225.1	16.1	15.5	4.2
1972	146	536	3231.2	1479.1	5390.0	174.4	89.4	234.2	17.1	16.5	5.1
1973	146	545	3938.5	1742.0	6635.7	190.4	106.1	253.5	18.6	17.6	6.4
1974	146	548	4687.2	1844.8	8438.9	207.5	113.6	279.6	19.1	17.9	7.0
1975	148	581	4642.7	1846.6	8746.0	226.2	120.2	316.6	17.7	16.8	7.1
1976	146	584	4913.2	1964.1	9248.8	245.4	129.0	352.4	17.8	17.0	8.1
1977	146	584	5549.8	2204.8	10557.1	268.7	138.8	394.2	18.1	17.3	5.5
1978	157	628	5983.0	2340.8	11845.3	283.9	144.4	426.7	18.3	17.4	5.7
1979	156	622	6906.6	2623.8	13824.9	318.3	158.5	479.7	18.6	17.7	6.2
1980	155	617	7766.1	2929.9	15393.9	356.5	178.4	538.4	18.6	17.5	6.0
1981	164	624	8695.8	3303.6	17064.1	401.6	195.9	609.8	18.5	17.2	6.1
1982	290	770	8047.5	3144.7	16409.3	386.0	190.4	640.0	18.3	17.1	7.1
1983	330	787	8547.6	3453.1	16721.5	437.8	207.3	731.9	17.9	16.9	6.8
1984	378	798	9320.6	3782.1	17592.4	478.2	223.6	783.6	18.2	16.9	8.0
1985	442	845	9862.2	4041.4	18370.0	524.0	247.3	853.6	18.9	16.6	17.6
1986	558	853	10924.2	4715.5	19738.5	607.0	291.4	979.2	18.8	16.4	15.2
1987	627	879	11644.7	4922.2	21131.5	617.3	301.3	950.9	18.6	16.0	11.7
1988	643	854	13032.8	5099.7	25726.7	702.0	308.5	1196.7	19.4	16.2	14.6
1989	675	843	14558.9	5243.4	30155.8	789.7	297.7	1373.3	20.2	16.1	21.8
1990	707	844	15749.0	4967.6	33335.1	866.6	302.2	1545.4	19.2	16.0	16.2
1991	755	869	15728.7	4676.8	34556.1	915.2	280.3	1666.8	19.1	15.4	39.0
1992	837	817	16898.2	4740.6	37177.9	1069.9	324.2	1994.6	15.5	14.3	11.2
1993	1015	1585	10215.2	1002.8	31799.4	683.1	79.8	1812.7	13.0	12.5	4.4
1994	1037	3280	5651.0	568.3	23574.0	391.7	51.4	1415.0	12.1	11.8	4.0
1995	940	3237	6379.8	556.7	28817.7	443.5	53.2	1720.9	11.4	11.3	3.9
1996	885	3078	7061.7	614.6	32239.1	492.8	58.7	1926.6	11.3	11.1	3.7
1997	853	2976	7952.3	681.2	36473.8	535.3	66.7	2084.7	11.4	11.1	3.8
1998	901	2947	10200.6	677.0	49801.4	640.4	68.0	2615.8	11.4	11.0	4.7
1999	970	3160	10872.2	636.9	56150.4	680.9	58.7	3008.6	11.7	11.3	4.7
2000	931	3419	11699.3	607.0	61812.9	719.7	53.8	3388.1	12.3	11.7	6.1
2001	945	3380	13527.1	637.4	71205.3	848.0	57.0	4190.8	12.1	11.4	8.8
2002	919	3277	16427.5	698.3	79420.4	1026.7	62.7	4759.0	12.3	11.4	20.1
2003	921	3302	20190.9	778.2	97645.0	1171.5	68.7	5401.4	12.5	11.5	19.5
2004	899	3179	22638.2	811.3	113936.9	1365.1	72.2	6981.8	12.3	11.4	13.1
2005	857	3128	28285.7	896.3	142986.0	1551.4	81.5	7602.6	12.2	11.3	13.8
2006	822	3026	33856.2	991.3	172961.4	1835.4	91.1	9106.9	11.8	11.1	5.3
2007	787	2908	41236.4	1046.2	224693.9	2120.6	97.8	10491.0	11.4	10.8	5.2
2008	756	2782	47944.6	1106.1	268072.6	2326.4	99.1	11816.0	12.1	11.2	5.8
2009	738	2662	49063.6	1195.5	264906.0	2739.6	105.1	15110.0	12.6	10.9	9.2
2010	735	2644	50894.5	1130.1	267429.2	3028.5	102.2	15764.0	12.6	10.5	13.1
2011	715	2587	61020.2	1117.8	308083.9	3599.7	112.1	17769.1	10.9	10.1	5.4
2012	742	2636	64506.7	1120.0	315693.1	3896.8	115.4	18798.7	10.5	9.7	4.7
2013	731	2590	67815.1	1198.5	315063.8	4263.3	127.1	19779.0	10.3	9.6	4.1
2014	707	2538	70072.3	1317.6	317166.4	4619.0	139.9	20997.3	9.9	9.4	3.3
2015	649	2270	73028.8	1592.0	311377.5	5144.6	178.2	22587.2	9.9	9.4	3.1

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