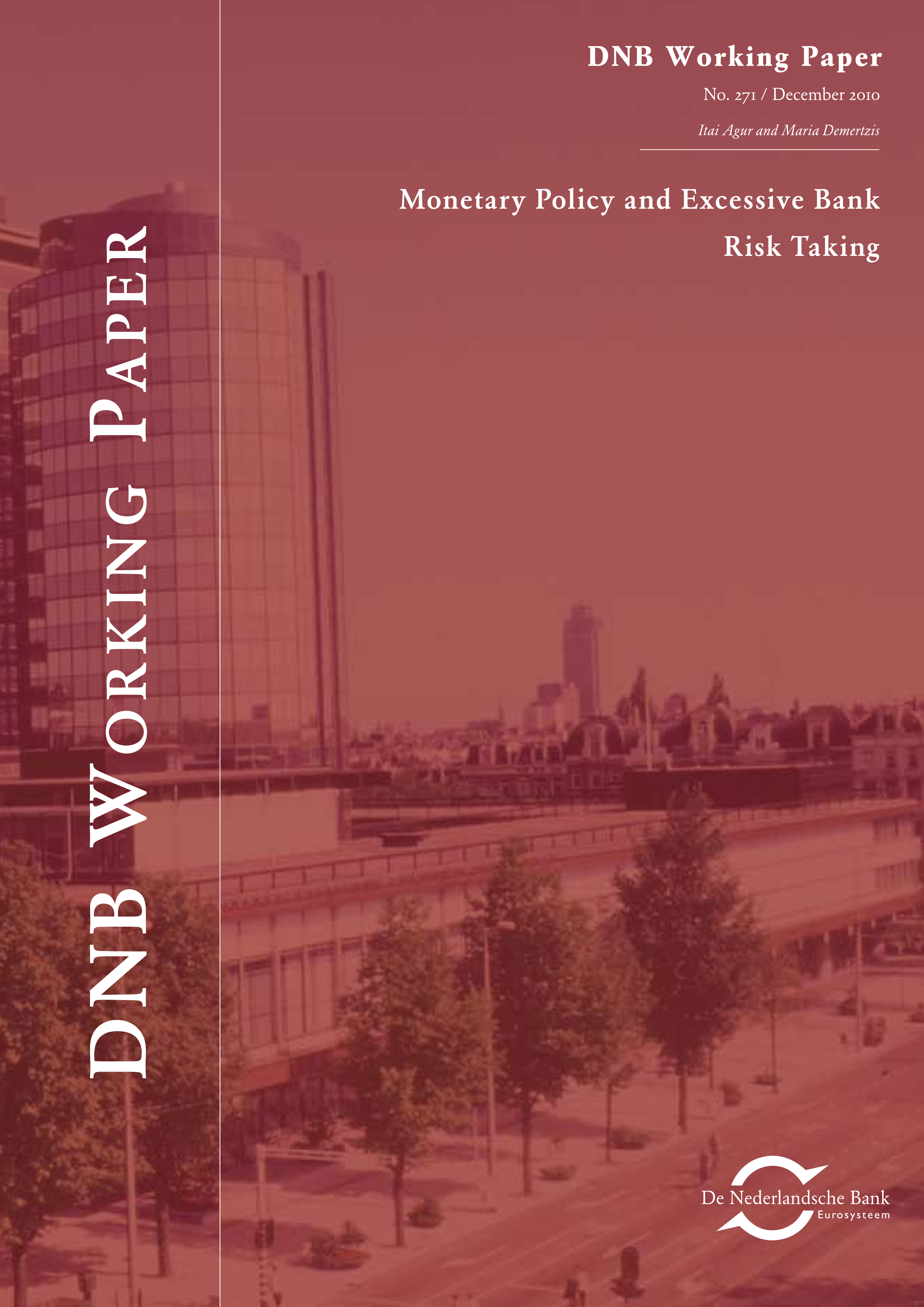

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Itai Agur and Maria Demertzis *

* Views expressed are those of the authors and do not necessarily reflect official positions of De Nederlandsche Bank.

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Monetary Policy and Excessive Bank Risk Taking*

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Abstract

This paper shows that a rate hike has countervailing effects on banks' risk appetite. It reduces risk when the debt burden of the banking sector is modest. We model a regulator whose trade-off between bank risk and credit supply is derived from a welfare function. We show that the regulator cannot optimally neutralize the welfare effects that the interest rate has through bank incentives. The larger the correlation between banks' projects, the more important the role for monetary policy. In a dynamic setting, not internalizing bank risk leads a monetary authority to keep rates low for too long after a negative shock.

Keywords: Monetary policy, Financial stability, Maturity mismatch, Leverage, Regulation

JEL Classification: E43, E52, E61, G01, G21, G28

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1 Introduction

Various authors have argued that in the runup to the recent crisis the US Fed's accommodative policies spurred risk taking incentives among financial intermediaries.[1] This paper models a transmission channel from the policy rate to bank risk taking, and uses it to analyze the interaction between monetary policy and regulation. The channel works through the funding side of banks, and the complementarity between leverage and asset risk.

The model contains banks that are heterogeneous in their cost efficiency. They are risk neutral and can choose between two types of bank-specific projects. The "excessive risk" project has a lower NPV than the "good" project, but because of the option value created by limited liability banks value its volatility. Efficient banks have high charter values - their options are deep in-the-money - and they select the good profile. Less efficient banks choose the bad profile instead.

Jointly with their asset profile, banks choose how much leverage to take on. Banks enter with a fixed amount of equity. Their debt is financed by a perfectly competitive market of creditors, who are partially secured by external deposit insurance (or, equivalently, face a positive probability of bailout upon bank failure). The marginal benefit of raising debt is constant: it allows the bank to expand its balance sheet and invest more in its project. Instead, the marginal cost is rising, because credit risk premia increase, as the bank becomes less likely to meet its expanding obligations. This trade-off determines each bank's optimal leverage ratio. At given leverage, the trade-off between the good and the bad project is that the first offers higher unconditional returns, but the latter better upside potential while part of the downside is not internalized in credit risk premia, because of the safety net. The more levered banks are, the more their trade-off leans towards excessive risk.

The policy rate affects risk taking through three types of channels: a substitution effect, price effects, and the extensive margin. The substitution effect is most obvious: when debt becomes more expensive, banks want less of it, as also confirmed in the empirical work on monetary policy and leverage of Adrian and Shin (2008, 2009a,b), Angeloni et al. (2010) and Dell'Arricia et al. (2010). But for a given debt level, a higher policy rate implies increased debt service costs - both directly by affecting the outside option of holding a risk-free asset, and indirectly by raising credit risk premia. Through price effects a rate hike enlarges banks' debt burden. If the substitution effect dominates, then a rate hike reduces the overall debt burden and simultaneously makes banks less inclined to choose the bad profile. The threshold efficiency above which the good profile is chosen declines. We derive a condition for this to be true and show that it is more likely to hold when the initial level of debt is low. In policy

[1] These include Borio and Zhu (2008), Dell'Ariccia et al. (2008), Calomiris (2009), Brunnermeier (2009), Brunnermeier et al. (2009), Taylor (2009), Allen et al. (2009), Adrian and Shin (2009a), Diamond and Rajan (2009) and Kannan et al. (2009).

terms, the beginning of a leverage cycle is when a rate hike would be most effective at reducing risk buildup. Finally, when rates rise, charter values fall and the least efficient, riskiest banks exit the market.

We embed the banking model in a static macro model. Instead of two types of projects there are two types of firms which a bank can fund. The firms have stochastic productivity identical to the project returns in the banking model. They produce a homogeneous good under decreasing returns to scale. Bank finance is the only source of firm funding. Labor supply is inelastic and consumers have linear preferences. We use the model to microfound the optimization problem of a regulator, who sets a maximum leverage ratio. Capping leverage at a lower level induces a trade-off: credit supply falls, downsizing firms, and reducing labor demand; but loan allocation improves, because banks invest in less risky firms. These firms have a lower volatility of productivity, which, because of decreasing returns to scale, raises the marginal product of labor on average. To our knowledge, this is the first paper to derive the regulator's risk reduction versus credit supply trade-off from a welfare function. We initially abstract from the feedback of bank profits to the consumer's budget constraint, but we prove robustness to general equilibrium in an appendix.

We conduct comparative statics to the policy rate. We show that its effects on welfare through bank decisions cannot be undone by optimal regulation. The reason is that monetary policy affects both sides of the regulator's trade-off. Since the policy rate works through different mechanisms than the leverage cap, the derivatives of bank risk and credit supply to the two tools are different. The regulator has no way to adjust his tool to completely neutralize the impact of monetary policy on bank incentives and, through them, on welfare. This finding backs up calls that monetary policy should in the future "lean against wind", that is, explicitly consider financial stability as part of its objective (Borio and White (2004), Disyatat (2010), Borio and Zhu (2008), Adrian and Shin (2008, 2009a,b)).[2]

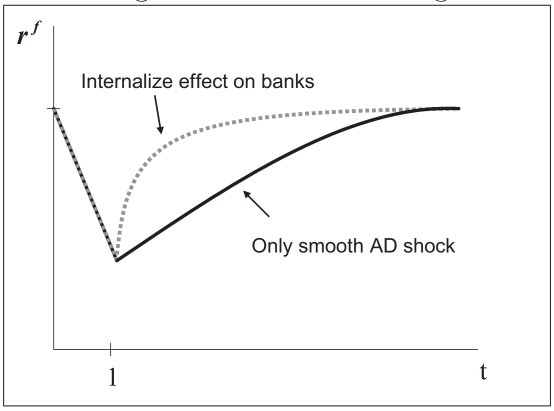
Initially we assume that firms' technology parameters are independent variables. But we extend to a common shock, creating positive correlation between bank funded projects. The shock comes from a symmetric distribution with zero mean. Nonetheless, it qualitatively affects our results. The larger the likelihood of a common shock, the greater the welfare effects that monetary policy has through bank incentives. Because of firms' decreasing returns to scale, very negative technology realizations imply great losses. The probability of such outcomes increases in the combination of greater exposure to the common shock and more banks selecting the volatile-efficiency firm type.

Next, we make the model dynamic and introduce an endogenous monetary authority. We add an endowment income for consumers, whose value depends upon the policy rate and

[2] See also Loisel et al. (2009) for a model in which it is optimal for the monetary authority to lean against asset bubbles by affecting entrepreneurs' cost of resources to prevent herd behavior.

a shock parameter. In conjunction with concave intertemporal preferences, smoothing the endowment shock provides the rationale for the use of the policy rate. We also introduce a maturity mismatch: banks relationships to firms are long term, but they can reoptimize their liabilities every period. If a bank defaults its point on the efficiency continuum and its asset structure are taken over by another bank next period. We consider two policy environments. One - the social optimum - in which monetary policy and regulation are jointly set. And one in which monetary policy only smooths the endowment income, while the regulator "cleans up" the interest rate's effects on banks' incentives as best it can. We show that in the latter environment the policy rate remains low for too long after a negative shock. Because of the long duration of assets, banks will only shift their portfolio towards more risk if they foresee a long rate cut. When monetary policy and regulation are jointly set, the policy rate rises faster, therefore. This is shown in figure 1.

Figure 1: low for too long



Interestingly, this result can be linked to empirics. There is a blossoming empirical literature on the relationship between monetary policy and bank risk, including Jiménez et al. (2009), Iaonnidou et al. (2009), Maddaloni and Peydro (forthcoming), Altunbas et al. (2010), Dell'Arricia et al. (2010), Buch et al. (2010), Delis and Brissimis (2010) and Delis and Kouretas (forthcoming). These papers use various types of data - ranging from credit registers, to bank lending surveys and bank balance sheet data - to show that a decline in the policy rate induces banks to take more risk. Importantly, two of these papers, namely Maddaloni and Peydro (2009) and Altunbas et al. (2010), find evidence that it not only matters whether rates are cut, but also how long they are kept low.

Our work is most closely related to the papers by Dell'Arricia et al. (2010), De Nicolò (2010) and Acharya and Naqvi (2010). These authors restrict their attention to modelling the transmission channel from monetary policy to bank risk. Dell'Arricia et al. (2010) model the policy rate's countervailing effects through bank levering and charter values. The latter is like our price effects. However, Dell'Arricia et al. provide a full analytical solution, whereas we can only derive comparative statics without closed-form expressions. The reason is that our optimization includes a kink (the default point), while theirs has an embedded probability of default. De Nicolò (2010) models a dynamic game in which charter values and bank market shares are endogenously determined. Low charter value banks disappear over time, especially if the policy rate is high. We also have the extensive margin effect, but we do not have endogenous market shares: each bank is tied to a given firm and we thus abstract from competition for borrowers. In Acharya and Naqvi (2010) bank loan officers are compensated on the basis of generated loan volume. When macroeconomic risk rises, a flight to safety occurs, raising bank deposits, which induces excessive credit volume and asset bubbles. Optimally, a monetary authority would "lean against liquidity". We go beyond these papers in linking the banking model to a simple macro model, and deriving optimal regulatory and monetary responses.

On the macro side there have recently been many papers that expand on the framework of Bernanke et al. (1999) to build financial frictions into DSGE models. These are reviewed in Gertler and Kyotaki (2010). But, for the most part, banks are a passive friction in this literature. Exceptions to this are Angeloni and Faia (2009), Angeloni et al. (2010) and Gertler and Karadi (2009) who construct macro models with decision taking banks. However, all risk taking occurs on the liability side of banks. The complementarity between leverage and asset risk choice cannot currently be incorporated into these model, because limited liability (or option valuation more generally) introduces a kink in the optimization which cannot be linearized.[3] Our approach is richer on the banking side, but much more limited on the macro. We thus see the two approaches as complementary.

Complementary also is the argument - so far unmodelled - that policy rates directly raise risk taking incentives by causing a search-for-yield (Rajan, 2005), instead of the funding side channel we consider. Apart from work on the ex-ante risk incentive effects of monetary policy, Diamond and Rajan (2008) and Farhi and Tirole (2009) analyze the optimality of using interest rates as an ex-post bailout mechanism. Our work also relates to the research on the pros and cons of conducting monetary policy and bank regulation at the same institution (Goodhart and Schoenmaker (1995), Peek et al. (1999), Iaonnidou (2005)).

The next section presents the bank model. Section 3 introduces an optimizing regulator, considers its interaction with the policy rate, and extends to correlated bank returns. Section 4 then makes the model dynamic and adds an endogenous monetary authority. Finally, section 5 discusses policy implications.

[3] But see Brunnermeier and Sannikov (2010) for a macro model that includes a financial sector and is not linearized.

2 Bank model

The idea of excessive bank risk taking is formalized in a simple way. There are two projects from which a bank can choose: the "good" project, g, and the "bad" project, b. The good project offers both a higher mean return and a lower volatility:

$$\mu_g > \mu_b \tag{1}$$

and

$$\sigma_g < \sigma_b \tag{2}$$

A risk-neutral investor would thus always prefer the good project. However, banks are different because of their limited liability. This essentially makes bank shareholders the owners of a call option. With high returns they repay debtholders and still reap much for themselves, while with low returns they default. Assuming that bank management represents risk-neutral shareholders, banks like volatile returns, therefore. From a bank's perspective the trade-off is between the benefit of the good project's higher return and the cost of its smaller volatility.

The idea that banks choose a project involves two implicit simplifications from a structure that explicitly models borrowers. Firstly, it is as if banks own the equity of borrowers. Secondly, there is no competition for borrowers between banks. What we wish to capture is that banks choose the riskiness of their asset profile, and that this choice interacts with their simultaneous levering decision. The intuition, we believe, is sufficiently strong to survive the additional complexities that would be introduced by borrowers with their own limited liability, and competition between banks for them. Thus, for instance, if bank borrowers also have the option to default, this makes the bank dislike overly volatile returns amongst them. Nonetheless, when the bank is itself more levered, it will dislike that volatility less. The direction of comparative statics is unaffected.

A Bank return

Each bank has a return function

$$R_i(k_i) = h(R(k_i), \varphi_i) \tag{3}$$

where $k_i \in \{g, b\}$ is the project choice of bank i and $R(g)$ and $R(b)$ are the distributions of returns on the good and the bad project, respectively. These have the properties given by (1) and (2). Moreover, φ_i is the bank's efficiency parameter, which is drawn from the distribution of banks' efficiency, $\gamma(\varphi)$. This distribution is assumed to be sufficiently wide to allow for the endogenous separation of banks (Lemma 3): the most efficient choosing the good project, less efficient the bad project, while the least efficient exit the market. The parameter can be thought of as a bank's cost efficiency in handling a project. A larger φ_i unambiguously improves a bank's return distribution, $R_i(k_i)$. When $\varphi_2 > \varphi_1$ it means that $R_2(k_2)$ first-order stochastically dominates $R_1(k_1)$. Formally, for any $y > 0$:

$$H(y, \varphi_2) < H(y, \varphi_1) \tag{4}$$

where $H(R(k), \varphi_i)$ is the cumulative distribution function of $h(R(k), \varphi_i)$. Note that this formulation nests the possibility that the bank efficiency only changes the mean return on projects, while leaving volatility unchanged. Examples are $R_i(k_i) = R(k_i) + \varphi_i$ and $R_i(k_i) = R(k_i) - \frac{1}{\varphi_i}$.

B Leverage

On the liability side banks have a fixed amount of equity, $\bar{e}$, the returns on which are purely the residual (no promised dividend payments). The issuance of additional external equity is assumed to be too costly. This is a reduced form departure from the Modigliani-Miller world with irrelevant capital structure. It is used elsewhere in the banking literature (see for example Thakor (1996) and Acharya et al. (2010)). The implicit (unmodelled) argument is that there are reasons, such as the Myers and Majluf (1984) signalling cost under asymmetric information, that make external equity too expensive.

A bank chooses how much debt, d_i, it want. This determines the size of its balance sheet:

$$x_i = \bar{e} + d_i \tag{5}$$

Bank debt is held by risk-neutral investors who are active on a perfectly competitive (and perfectly informed) financial market. These investors cannot undertake projects by themselves. Implicitly, intermediation through the banking sector is necessary because banks have a monitoring advantage as compared to dispersed investors (Diamond (1984)).

Bank debt is partly secured by an externally financed guarantee (for the existence of which the model provides no justification). In the event of bank default the creditors receive back a share $\beta \in (0, 1)$ of their investment. This could be either a deposit guarantee or the ex-ante expected probability of a bailout. We require $\beta \neq 1$ and $\beta \neq 0$. Under full guarantee, $\beta = 1$, investors charge no credit risk premia and the optimal leverage ratio would be indeterminate. Instead, under $\beta = 0$ market discipline is so stringent that no bank would select the bad project.

Debt claimants demand a fair premium above the risk-free rate, r^f, to compensate for the probability that they lose their investment. In particular, the interest rate on bank i's debt,

r_i^d has to satisfy:

$$\begin{aligned}(1-q_i)\left(1+r_i^d\right)+q_i\beta\left(1+r_i^d\right) &= 1+r^f \\ r_i^d &= \frac{1+r^f}{1-q_i(1-\beta)}-1\end{aligned} \tag{6}$$

where q_i is the probability that bank i will default:

$$q_i = \Pr\left[x_i R_i(k_i) - d_i\left(1+r_i^d\right) < 0\right] \tag{7}$$

As $x_i R_i(k_i) - d_i\left(1+r_i^d\right)$ is bank i's revenues minus what it must repay debtholders.

In taking on more debt a bank thus faces the following trade-off. On the one hand, with more leverage a bank expands the size of its balance sheet. The amount that it can take on of its chosen project is x_i. The marginal benefit of more debt is thus constant ($E[R_i(k_i)]$). But the marginal cost is increasing. As the initial equity is costless, the cost of debt determines a bank's cost of capital. And for any $\beta < 1$ the cost of debt is rising in the amount of debt issued, as the equity cushion becomes relatively smaller, and the probability of default rises. With a constant marginal benefit, but rising marginal cost, there exists an optimal degree of leverage, as proven formally in Lemma 2.

C Bank maximization

Bank management maximizes profits to its two decision variables: k_i (the project choice), d_i (leverage):

$$\max_{k_i,d_i}\left\{E\left[\max\left\{x_i R_i(k_i) - d_i\left(1+r_i^d\right),0\right\}\right]\right\} \tag{8}$$

Replacing from (3), (5) and (6) we can rewrite the problem to

$$\max_{k_i,d_i}\left\{E\left[\max\left\{(d_i+\bar{e})\,h(R(k_i),\varphi_i) - d_i\left(\frac{1+r^f}{1-q_i(1-\beta)}-1\right),0\right\}\right]\right\} \tag{9}$$

given

$$q_i = \Pr\left[(d_i+\bar{e})\,h(R(k_i),\varphi_i) < d_i\left(\frac{1+r^f}{1-q_i(1-\beta)}-1\right)\right] \tag{10}$$

This problem cannot be solved by taking derivatives. Firstly, the max operator for profits is a kinked function. And, secondly, q_i is a function of itself, and, for given functional forms, would need to be solved for numerically. However, we can show that there exists a fixed point for q_i between 0 and 1 (Lemma 1) and that there exists an optimal debt level, d_i^* (Lemma 2). More importantly, we can prove the separation of banks according to efficiency in optimal project choice, k_i^* (Lemma 3).

Lemma 3 shows that there exist two thresholds for bank efficiency, $\overline{\varphi}^l$ and $\overline{\varphi}^h$. The least efficient banks ($\varphi_i < \overline{\varphi}^l$) leave the market, because their charter value is negative (expected returns would not cover required repayments to creditors). Banks with intermediate efficiency ($\varphi_i \in \left(\overline{\varphi}^l, \overline{\varphi}^h\right)$) choose the bad project, $k_i^* = b$. And the most efficient banks ($\varphi_i > \overline{\varphi}^h$) choose the good project, $k_i^* = g$. Intuitively, volatility is only valuable to banks because of their limited liability. But the more efficient and profitable they are, the less their limited liability matters, since default becomes less likely. In option valuation terms, efficient banks have call options that are deeper in-the-money. The benefit of the bad project is its larger volatility, coupled with the fact that the downside is not fully internalized in credit risk premia because of the safety net. This benefit thus becomes smaller for more efficient banks, so that the higher unconditional returns of the good project become more attractive to them.[4]

We can use Lemma 3 to define a measure of excessive risk taking in the banking sector. It is the share of active banks that chooses the bad project:

$$\frac{\int_{\overline{\varphi}^l}^{\overline{\varphi}^h} \gamma\left(\varphi\right) d\varphi}{\int_{\overline{\varphi}^l}^{\infty} \gamma\left(\varphi\right) d\varphi} \tag{11}$$

Intuitively, this measure rises when $\overline{\varphi}^h$ rises (fewer banks select the good project), while it falls when $\overline{\varphi}^l$ rises (exit of inefficient banks leaves fewer active banks with the bad project).

Lemma 1 *It holds that $q_i \in (0, 1)$.*

Proof. The solution to equation (10) must involve the equalization of the left-hand and right-hand sides. This cannot happen at $q_i = 0$, for at that value the left-hand side equals zero, but the right-hand side ($\Pr\left[\cdot\right]$) is positive. But it also cannot happen at $q_i = 1$ as then the right-hand side is smaller than one. Therefore, $q_i \in (0, 1)$. ■

Lemma 2 $\exists d_i^* \in [0, \infty)$.

Proof. This follows directly from the fact that $h(R\left(k_i\right), \varphi_i)$ is constant in d_i, whereas $\left(\frac{1+r^f}{1-q_i(1-\beta)} - 1\right)$ rises in d_i, because q_i is positively related to d_i. ■

Lemma 3 *Banks choose their asset profile according to their efficiency:*

1. $\varphi_i < \overline{\varphi}^l \Rightarrow k_i^* = \emptyset$
2. $\varphi_i \in \left(\overline{\varphi}^l, \overline{\varphi}^h\right) \Rightarrow k_i^* = b$
3. $\varphi_i > \overline{\varphi}^h \Rightarrow k_i^* = g$

[4] Lemma 3 resembles the result of the seminal Melitz (2003) model of heterogeneous firms in international trade. There, the most efficient firms self select into becoming exporters, less efficient firms serve only for the domestic market, and the least efficient exit (though driven by fixed costs rather than volatility and option values).

where $\varphi_i = \overline{\varphi}^l$ is the bank that is indifferent between inactivity or activity with $k_i^* = b$, while $\varphi_i = \overline{\varphi}^h$ is the bank that is indifferent between the two projects, b and g.

Proof. The existence of $\overline{\varphi}^l$ is straightforward: by (4), when efficiency is so low that, in expectation, $h(R(k_i), \varphi_i)$ does not cover $d_i r_i^d$ then operating the bank yields negative expected return to shareholders, and it is closed down. More intricate is the case of threshold $\overline{\varphi}^h$. The value of project b to the bank arises from $\sigma_g < \sigma_b$ in conjunction with limited liability. This creates the call option structure $E[\max\{z, 0\}]$ in which volatility is of value. Here z is the underlying asset of the option. By the standard arguments of option value theory (Hull, 2002), the volatility of z is worth more when the option is less in-the-money (when z is closer to 0). Intuitively, for $z \to \infty$ owning a call option is just like owning the underlying asset, as the option will certainly be exercised. The possibility not to exercise the option - here: the possibility to default - only matters when z is not too far above 0. In (9)

$$z = (d_i + \overline{e})\, h(R(k_i), \varphi_i) - d_i \left(\frac{1 + r^f}{1 - q_i(1 - \beta)} - 1 \right) \tag{12}$$

where $h(R(k_i), \varphi_i)$ is increasing in φ_i (by (4)). And, as can be seen in (10) q_i falls in φ_i, which implies that $\frac{1+r^f}{1-q_i(1-\beta)}$ falls and therefore z increases. Hence, z is monotonically increasing in φ_i. As a higher z reduces the value of volatility, it reduces the value to the bank of project b as compared to project g. Therefore, beyond a threshold $\overline{\varphi}^h$ banks will choose $k_i^* = g$. ■

D Monetary policy

The policy rate of monetary authorities - such as the Federal funds rate in the US or the repo rate in the eurozone - directly affects the cost of short-term wholesale bank funding. In the context of the model we make r^f the policy rate. In this section we keep the monetary authority itself exogenous. We simply perform comparative statics of the model with respect to the policy rate. The aim is to show how monetary policy can affect bank risk taking within the mechanism described above.

Proposition 1 *Monetary policy affects bank risk choice through four channels:*

1. *It affects the cost of debt funding directly*
2. *It affects this cost indirectly through credit risk premia*
3. *It affects the optimal debt choice of the bank*
4. *It pushes banks into / out of activity*

For the first two channels $\frac{\partial \overline{\varphi}^h}{\partial r^f} > 0$: higher policy rates raise average bank risk. Instead, through the third channel $\frac{\partial \overline{\varphi}^h}{\partial r^f} < 0$ and monetary tightening makes fewer banks take on excessive risk.

The overall sign of $\frac{\partial \overline{\varphi}^h}{\partial r^f}$ is ambiguous. However, $\frac{\partial \overline{\varphi}^l}{\partial r^f} > 0$ is unambiguous: higher policy rates push more banks into inactivity, which by $\overline{\varphi}^h > \overline{\varphi}^l$ means that excessive risk banks exit.

Proof. Channel 1 and 2 follow from the fact that a higher r^f increases $\frac{1+r^f}{1-q_i(1-\beta)}$ in two ways. Channel 1: the numerator rises. Channel 2: the denominator falls, because q_i in equation (10) increases when r^f increases. Following the argument in the proof of Lemma 3, when $\frac{1+r^f}{1-q_i(1-\beta)}$ rises volatility becomes more valuable to a bank. Its limited liability call option is less in-the-money, as can be seen from equation (12). Therefore, banks will require a higher efficiency φ_i to be willing to take up the good project. This means that the threshold $\overline{\varphi}^h$ rises: among active banks, more banks select the bad project. Channel 3 follows from the fact that

$$\arg\max_{d_i} E\left[\max\left\{(d_i + \overline{e})\, h(R(k_i), \varphi_i) - d_i\left(\frac{1+r^f}{1-q_i(1-\beta)} - 1\right), 0\right\}\right]\Bigg|_{k_i}$$

falls when $\frac{1+r^f}{1-q_i(1-\beta)}$ rises: the bank substitutes away from debt when it becomes more expensive. Through this channel $d_i \frac{1+r^f}{1-q_i(1-\beta)}$ falls in equation (12), and by the inverse of the argument above this means that $\overline{\varphi}^h$ declines: a larger fraction of active banks chooses the good project. Finally, $\frac{\partial \overline{\varphi}^l}{\partial r^f} > 0$ follows from the fact that a higher r^f is an additional cost to a bank. Therefore, the charter value of a bank declines. This means that a bank requires a higher efficiency to be able to offer positive expected profits, so that $\overline{\varphi}^l$ rises. This is the fourth channel. ■

A bank's indebtedness and its incentive to take asset side risk are positively related. The key question is thus how monetary policy impacts upon banks' debt burden. As Proposition 1 shows, the answer is threefold. Firstly, there is a direct price effect. Bank funding becomes more expensive, because the opportunity cost of holding bank debt increases - risk-free assets offer higher returns than before. Secondly, because funding costs rise, the probability that a bank will be able to repay its obligations declines (charter values fall). Default becomes more likely, and the risk premium that debtholders demand on bank debt increases. But, thirdly, there is a substitution effect. As the price of debt rises, banks want to hold less of it. With less debt issued but higher debt service costs, what happens to the overall debt burden of banks is ambiguous. Finally, when rates rise banks become less profitable overall and the least efficient active banks will exit. These banks self selected into the bad project, so that the share of active banks taking on excessive risk falls through this channel.

The crucial question is therefore under which condition a rate hike will translate into less bank risk taking, as found by the empirical literature discussed in the introduction. We provide a sufficient (but not necessary) condition in Proposition 2. It relies on Condition 1 below. Proposition 2 is based on a hypothetical derivative. That is, d_i^* is known to exist and we consider its derivative to r^f even if we do not have a closed form solution for d_i^*.

Interestingly, the sufficient condition that Proposition 2 derives, shows that the effect of a rate cut on risk taking depends on the level of debt, d_i^*. When the threshold bank $\overline{\varphi}^h$ is heavily levered, a rate hike strongly reduces its charter value. The price effects (channels 1 and 2) in Proposition 1 gain importance. This works against the substitution effect (channel 3). From this perspective, if the monetary authority aims at reducing excessive risk in the banking sector, the right moment for a rate hike is when leverage among banks is still relatively low. That is, at the beginning of a leverage cycle (not modelled in this paper).

Condition 1 *$R_i(k_i)$ are bell shaped and bank default is a left-tail event: $\frac{\partial q_i}{\partial r^f} \to 0$.*

Proposition 2 *Given condition 1, a sufficient condition for excessive risk (as defined by (11)) to fall in the policy rate is that for threshold bank i with $\varphi_i = \overline{\varphi}^h$:*

$$\left|\frac{\partial d_i^*}{\partial r^f}\right| > \frac{d_i^*}{1+r^f} \tag{13}$$

Proof. Though d_i^* cannot be analytically derived, Lemma 2 shows that it exists. The total indebtedness of a bank

$$d_i^* \frac{1+r^f}{1-q_i(1-\beta)}$$

would fall in r^f if and only if

$$\frac{\partial d_i^*}{\partial r^f}\frac{1+r^f}{1-q_i(1-\beta)} + \frac{d_i^*}{1-q_i(1-\beta)} < 0$$

where the term with $\frac{\partial q_i}{\partial r^f}$ has been cancelled by condition 1. This can be rewritten to

$$\frac{\partial d_i^*}{\partial r^f} < -\frac{d_i^*}{1+r^f} \Rightarrow \left|\frac{\partial d_i^*}{\partial r^f}\right| > \frac{d_i^*}{1+r^f}$$

and given (by Proposition 1) that $\frac{\partial d_i^*}{\partial r^f}$ is negative, this can be written to

$$\left|\frac{\partial d_i^*}{\partial r^f}\right| > \frac{d_i^*}{1+r^f}$$

If this holds for bank i with $\varphi_i = \overline{\varphi}^h$ then this condition is sufficient for $\frac{\partial \overline{\varphi}^h}{\partial r^f} < 0$. And given that the fourth channel of Proposition 1 unambiguously implies $\frac{\partial \overline{\varphi}^l}{\partial r^f} > 0$ then it follows that the above condition is also sufficient for

$$\frac{d}{dr^f}\left[\frac{\int_{\overline{\varphi}^l}^{\overline{\varphi}^h} \gamma(\varphi)\, d\varphi}{\int_{\overline{\varphi}^l}^{\infty} \gamma(\varphi)\, d\varphi}\right] < 0$$

■

3 Regulation

Having established the channels at work in the banking model, we now integrate it within a simple macro model. The primary goal of the macro model is to justify the objective function of a regulator.

A Macro model

Instead of projects, banks now invest in output-producing firms. Each bank invests in one firm. There are two types of firms, corresponding to the two types of projects before. The efficiency with which firms produce output is a stochastic variable, given by $R(k)$ with "good" firms producing according to $k = g$ and "bad" firms according to $k = b$. First banks choose the type of firm they invest in and provide funds to it, then the firm's technological efficiency is realized. The output of firm type k, financed by bank i, is

$$\sqrt{R(k_i)(d_i + \bar{e})\, l_i^d} \tag{14}$$

All firms produce the same homogeneous good, and they do so with a decreasing returns to scale technology. Here, l_i^d is the labor input of the firm financed by bank i. Moreover, $(d_i + \bar{e})$ is the amount of funding that the firm receives from the bank. In other words: $(d_i + \bar{e})$ is the capital input, l_i^d is the labor input, while $R(k_i)$ is the technological efficiency. Firms' efficiency draws are uncorrelated, $E[R(k_i)|\, R(k_j)] = E[R(k_i)]$. This assumption is relaxed in section 5.

There exists no form of financing for firms other than bank finance. Therefore, the only active firms are those which banks choose to finance. Moreover, as banks are the only financiers, they appropriate the entire profit of firms (as before: banks are modelled as firm owners). The profit of a firm is given by

$$p\sqrt{R(k_i)(d_i + \bar{e})\, l_i^d} - w l_i^d \tag{15}$$

where p is the price of the good and w is the market wage rate.

There is an atomistic consumer with linearly increasing utility in the good, and with a fixed, inelastic labor supply, normalized to one, $l^s = 1$. He spends his entire income, $(1)\,\frac{w}{p}$, on the good. As there is only one good, its price functions as numeraire, and can be normalized to $p = 1$.

In this section we abstract from wealth effects. We assume that bank shareholders, bank creditors and the deposit guarantee scheme (or bailout scheme) that covers creditors are foreign. However, in an appendix we make them all domestic and integrate the general equilibrium feedback, showing that results are unaffected.

Labor demand is obtained from the first order condition of profits to l_i^d, which yields

$$l_i^d = \frac{1}{4w^2} R(k_i)(d_i + \overline{e}) \tag{16}$$

Total labor demand can be expressed as $\int_i l_i^d di$ and the labor market equilibrium is given by

$$\int_i \frac{1}{4w^2} R(k_i)(d_i + \overline{e})\, di = 1 \tag{17}$$

which can be written to

$$w = \frac{1}{2}\sqrt{\int_i R(k_i)(d_i + \overline{e})\, di} \tag{18}$$

Since the consumer's utility is linear in $\frac{w}{p}$, his welfare can be expressed as the above term. Expected utility, $E[u]$ can then be written as:

$$E[u] = \frac{1}{2} E\left[\sqrt{\int_i R(k_i)(d_i + \overline{e})\, di}\right] \tag{19}$$

and, therefore, consumer welfare is directly determined by bank choices on which types of firms to fund and how much leverage to take on. In particular, when banks supply more credit $(d_i + \overline{e})$ firms' labor demand increases, which raises wages and thereby utility. Conversely, if banks fund riskier firms welfare is lowered. The reason is twofold. Firstly, the mean technological efficiency of bad firms is lower. Secondly, their productivity is more volatile. Even though the consumer is risk neutral, he dislikes volatility in the technology parameter, because of decreasing returns to scale. For example, a firm that always has technology parameter 10 produces more output on average than a firm that has a parameter of 5 half the time and 15 the other half.

Clearly, the second feature is more realistic than the first: risky firms offer more volatile output, but they are unlikely to have a lower mean productivity than safe firms. However, the first feature is necessary in a world with risk neutral banks, who like volatility because of limited liability. If the riskier firm offered higher mean returns, all banks would select this type.

The bank's expected profits are given by the expression below:

$$E\left[\max\left\{\left[\sqrt{R(k_i)(d_i + \overline{e})\, l_i^d} - w l_i^d\right] - \frac{1}{\varphi_i} - d_i\left(\frac{1 + r^f}{1 - q_i(1 - \beta)} - 1\right), 0\right\}\right] \tag{20}$$

where we have made a functional form choice for the way cost efficiency, φ_i, enters. Namely, we assume that there is a cost to operating a bank, $\frac{1}{\varphi_i}$, which decreases in the efficiency of a bank. Replacing from (16) we can write this to

$$E\left[\max\left\{\frac{1}{4w}\left(d_i+\overline{e}\right)R\left(k_i\right)-\frac{1}{\varphi_i}-d_i\left(\frac{1+r^f}{1-q_i\left(1-\beta\right)}-1\right),0\right\}\right] \tag{21}$$

where

$$q_i=\Pr\left[\frac{1}{4w}\left(d_i+\overline{e}\right)R\left(k_i\right)-\frac{1}{\varphi_i}<d_i\left(\frac{1+r^f}{1-q_i\left(1-\beta\right)}-1\right)\right] \tag{22}$$

Nothing in this formulation affects the proofs of Lemmas 1, 2 and 3. Therefore, the mechanisms identified in section 2 are unchanged.[5]

B Regulatory objective

We now introduce a regulator. His tool is a leverage cap: the regulator can state a maximum to the amount of debt that banks are allowed to take on, $\overline{d}$. His aim is to maximize the consumer's expected utility:

$$\max_{\overline{d}} E\left[u\right] \tag{23}$$

In setting the leverage cap the regulator faces the trade-off that we discussed below equation (19): firm quality versus credit supply. Forcing banks to delever, can help reduce their incentives to take on excessive risk. With more banks choosing good type firms, the volatility of technological efficiency falls, which raises output because of decreasing returns to scale. But as bank finance is the sole source of firm funding, shedding leverage also implies downsizing firms, which reduces labor demand.

Proposition 3 establishes under what condition the regulator's trade-off leads to an interior solution. That is, a leverage cap that is binding for at least some banks, but that is greater than zero. In the remainder of this paper we will assume that this condition is satisfied.

There are several points to note about the tool that we have given the regulator. Firstly, it is not the optimal tool in our setting. Given that we assume perfect information, the regulator could simply forbid banks from taking on the bad project, under threat of closure. This would obviously trivialize the model. To justify from microfoundations a more sophisticated tool would require the introduction of asymmetric information between banks and the regulator. This would add considerable complexity, however, without adding much insight to our results, we believe. We therefore choose the reduced route and simply restrict the regulator to the use of a leverage cap.

Secondly, the leverage cap is equivalent to a capital requirement without risk weights. As banks have a fixed amount of capital, a requirement that states the minimum fraction of

[5] Note that because there is a continuum of banks, an individual bank does not consider the impact of its decision on the wage rate, as given by equation (18).

liabilities that should be in equity effectively caps the amount of debt they can take on. A risk weighted capital requirement would trivially do better. The regulator could state that any bank that chooses to fund a bad type firm is faced with $\overline{d} = 0$. This is basically the same as shutting down banks that choose excessive risk, and thus brings us back to our previous point: to meaningfully introduce risk weighted capital requirements would require modelling asymmetric information.

Proposition 3 *An interior solution for the regulator ($\overline{d} > 0$ and $\overline{d} < d_i^*$ for some i) comes about when either $(\sigma_b - \sigma_g)$ or $\left(\mu_g - \mu_b\right)$ is sufficiently large.*

Proof. Firstly, $\overline{d} = 0$ can never be optimal for the regulator. The reason is that raising $\overline{d}$ up to the point that the one bank would choose $k = b$ would bring about an atomistic loss, but a discrete gain: the rest of the continuum of banks raises d_i increasing $\int_i R(k_i)(d_i + \overline{e})\, di$. Secondly, as $(\sigma_b - \sigma_g)$ rises the benefit of causing a fall in $\overline{\varphi}^h$ become larger, as can be seen from the square root term in equation (19). Similarly, when $\left(\mu_g - \mu_b\right)$ increases expected utility responds more strongly to a decline of $\overline{\varphi}^h$ because $E[R(k_i)]$ reacts more. When the benefits of correcting excessive risk taking incentives are large enough, $\overline{d} < d_i^*$ for some i will be optimal. ■

C Monetary policy

We now consider the interaction between exogenous monetary policy - changes in r^f - and optimal regulation. Proposition 4 establishes that the regulator cannot neutralize the welfare effects that monetary policy brings about through bank incentives. The reason is intuitive: monetary policy affects both sides of the regulator's trade off. Both loan quality and credit supply are affected. Unless both policy tools affect both of these variables identically - and they do not - then the regulator cannot "clean up" the impact that an exogenous change in monetary policy has on expected utility. That is, monetary policy affects welfare through bank incentives, even if there is an optimizing regulator.

Proposition 4 *The regulator's tool, $\overline{d}$, cannot neutralize the effects on expected utility brought about by changes in the policy rate, r^f. Monetary policy affects welfare through bank incentives even when there is regulation.*

Proof. Consider the general problem

$$\max_{x_1} f\left(y_1(x_1, x_2), y_2(x_1, x_2)\right)$$

Optimization towards x_1 yields

$$\frac{\partial f(\cdot)}{\partial y_1(x_1, x_2)} \frac{\partial y_1(x_1, x_2)}{\partial x_1} = -\frac{\partial f(\cdot)}{\partial y_2(x_1, x_2)} \frac{\partial y_2(x_1, x_2)}{\partial x_1}$$

Any exogenous change in x_2 affects both sides of the equation. For x_1 to be able to exactly offset any effects of x_2 on f it has to hold that

$$f\left(y_1\left(x_1^{*\prime}, x_2^{\prime}\right), y_2\left(x_1^{*\prime}, x_2^{\prime}\right)\right) = f\left(y_1\left(x_1^{*\prime\prime}, x_2^{\prime\prime}\right), y_2\left(x_1^{*\prime\prime}, x_2^{\prime\prime}\right)\right)$$

where $x_2^{\prime}$ and $x_2^{\prime\prime}$ are two different values of x_2, and $x_1^{*\prime}$ and $x_1^{*\prime\prime}$ are the respective optimization outcomes to x_1. This can only hold when:

$$\frac{\partial y_1\left(x_1, x_2\right)}{\partial x_2} = \frac{\partial y_1\left(x_1, x_2\right)}{\partial x_1} \wedge \frac{\partial y_2\left(x_1, x_2\right)}{\partial x_2} = \frac{\partial y_2\left(x_1, x_2\right)}{\partial x_1}$$

Since both r^f and $\overline{d}$ affect both the terms $R\left(k_i\right)$ and $\left(d_i + \overline{e}\right)$, the effect of a change in r^f on expected welfare $E\left[u\right]$ could only be neutralized by $\overline{d}$ if derivatives are symmetric as given above. But, clearly, they are not: the terms enter differently in (21). Therefore, $\overline{d}$ cannot effectively neutralize the effects that r^f has on $E\left[u\right]$ through bank behavior. ■

D Correlated returns

So far we have considered only microprudential risks, in the sense that firms' stochastic efficiencies, and thereby bank returns, are independent. Here we introduce positive correlation between bank financed projects. We let go of the assumption that $E\left[R\left(k_i\right) \middle| R\left(k_j\right)\right] = E\left[R\left(k_i\right)\right]$. A simple form to introduce positive correlation in our framework is to set the expected efficiency of a k type firm to: μ_k with probability $(1-\pi)$ and $\mu_k + \upsilon$ with probability π where υ is a random shock with zero mean.[6] That is, there is a common shock to which all firm efficiency distributions are subject. It either realizes or not. If it realizes then the distributions from which firms draw their efficiencies (i.e., stochastic variables $R\left(b\right)$ and $R\left(g\right)$) experience equivalent changes in the means, while variances remain constant. Overall: first banks' efficiencies are drawn from $\gamma\left(\varphi\right)$, then banks optimize choosing their leverage and firm type, then the means of $R\left(k\right)$ are determined (common shock realizes or not), and subsequently the idiosyncratic firm technology parameters are realized.

Proposition 5 shows that the impact of monetary policy on welfare rises in the correlation between banks' projects. When the probability of a common shock (π) rises, the most negative possible outcomes become more negative. As discussed before, decreasing returns to scale imply that expected utility declines in variability. Even though the common shock has a zero mean, it destroys value on average. But it does so most strongly for the worst realizations. The most negative outcomes can occur for the bad type firms: when a b type firm experiences a bad common shock and a bad idiosyncratic realization. Policies that affect the extent

[6]The same argument would hold if it were the volatilities σ_k which are hit by the common shock.

of risk taking by banks become more important for welfare when common shocks are more likely. By Proposition 4 the impact that monetary policy has on welfare cannot be undone by regulation. Hence, greater correlation between banks raises the impact that monetary policy has on welfare.

Proposition 5 *Greater correlation between banks' returns raises the impact of monetary policy on welfare:* $\left|\frac{\partial E[u]}{\partial r^f}\right|$ *increases in* π*.*

Proof. Consider the general concave function $f(x)$. There are two variables x_1 and x_2 where x_1 is more volatile than x_2. And some policy tool affects whether x_1 or x_2 is chosen (for an exogenous reason). Then if the volatility of both variables increases, $E[f(x_2)] - E[f(x_1)]$ rises, and the effects of the policy tool become more important. The same principle applies here. From equation (19) expected utility depends on the expected value of the term

$$\sqrt{\int_i R(k_i)(d_i + \bar{e})\, di}$$

which is a concave function. When π rises the volatility of $R(k_i)$ increase: they are more likely to be hit by the common shock, which will make values higher or lower. Therefore, the effects of any policy tool affecting the choice between $R(b)$ and $R(g)$ then have a greater impact upon $E[u]$. By Proposition 1 r^f affects this choice. And by Proposition 4 this effect cannot be neutralized by $\overline{d}$. ■

4 Dynamics

In this section we consider a dynamic specification of the model, with T periods. This allows us to introduce a monetary authority that responds to shocks, and analyze its interaction with the regulator. Compared to the static setting, the dynamic model adds two new elements: a consumer endowment that is subject to shocks, and long-term assets on banks' balance sheets. The consumer endowment makes the use of two tools - the interest rate and the leverage cap - meaningful. The presence of long-term bank assets allows us to draw inferences on the dynamics of optimal monetary policy. In particular, it establishes a connection to the empirical observation that keeping rates low for long can strongly spur bank risk taking incentives.

A Consumers and firms

We assume that consumers have endowment income in addition to labor income. This endowment income is given by $\lambda\left(r_t^f, \varepsilon_t\right)$ with $\frac{\partial \lambda\left(r_t^f, \varepsilon_t\right)}{\partial r_t^f} < 0$. The endowment can be thought of as a long term bond, whose value is negatively affected by a rise in short-term interest rates. In addition it is affected by a shock parameter, ε_t, following:

$$\varepsilon_t = \theta\varepsilon_{t-1} + \nu_0 \tag{24}$$

where $\theta \in (0,1)$ is a persistence parameter and ν_0 is the initial shock (we consider only a one time shock). Monetary policy can help smooth this shock, which has value to consumers, because they have concave intertemporal preferences:

$$U_t = \sqrt{u_t} \tag{25}$$

$$u_t = w_t + \lambda\left(r_t^f, \varepsilon_t\right) \tag{26}$$

where w_t is given by the labor market equilibrium

$$w_t = \frac{1}{2}\sqrt{\int_i R\left(k_{it}\right)\left(d_{it} + \overline{e}\right) di} \tag{27}$$

All consumer and firm decisions are a per period repeat of the static model. Consumers have no instrument with which to save income intertemporally: they consume all wage and endowment income instantaneously. Firms draw their efficiency parameter each period: their technology is stochastic over time.

B Banks

Banks relation to firms is long term. A bank can only change the type of firm it finances once every N periods. It can, however, re-optimize its financing choice every period (there is a maturity mismatch). Crucially, banks do not retain any earnings. At the end of each period they pay out all their profits to their shareholders, or, if they cannot meet their obligations, they default. Here we require the assumption that if any bank defaults it is replaced next period by an equivalent bank, to prevent holes in the continuum of $\gamma(\varphi)$. The replacing bank takes over the relationship to the defaulted bank's firm, so that it re-optimizes at the same time as all other banks. Note that because banks are atomistic, each takes the policies of the monetary authority and the regulator as given. There are no strategic interactions between banks and policy makers, that is, because banks do not consider how their decisions affect those of the policy makers. The optimization problem of a bank becomes:

$$\begin{aligned}
&1.\ \max_{d_{it},k_{it}} E\left[\sum_{t'}^{t'+N}\delta^{t-t'}A_t\left[\max\left\{\tfrac{1}{4w_t}\left(d_{it}+\overline{e}\right)R\left(k_{it}\right)-\tfrac{1}{\varphi_i}-d_{it}\left(\tfrac{1+r_t^f}{1-q_{it}(1-\beta)}-1\right),0\right\}\right]\right]\\
&2.\ \max_{d_{it}} E\left[\max\left\{\tfrac{1}{4w_t}\left(d_{it}+\overline{e}\right)R\left(k_{it}\right)-\tfrac{1}{\varphi_i}-d_{it}\left(\tfrac{1+r_t^f}{1-q_{it}(1-\beta)}-1\right),0\right\}\right]
\end{aligned} \tag{28}$$

where 1. occurs when $t\prime$ is multiple of N and 2. otherwise, and

$$q_{it}=\Pr\left[\frac{1}{4w_t}\left(d_{it}+\overline{e}\right)R\left(k_{it}\right)-\frac{1}{\varphi_i}<d_{it}\left(\frac{1+r_t^f}{1-q_{it}\left(1-\beta\right)}-1\right)\right] \tag{29}$$

and $\delta\in(0,1)$ stands for the discount rate and A_t is an indicator variable taking value 0 if default occurred in any previous period and 1 otherwise.

C Policy makers

The timing of the game we consider is as follows:

Table 1: the timing of the game

$t=0$	1. Shock ν_0 realized	
	2. Policy makers separately or jointly set paths for r_t^f and $\overline{d}_t$	
$t=1$	1. Simultaneously:	a. Banks set $d_{it}\leq\overline{d}_t$
		b. Set k_{it}
	2. Bank returns realized	
	3. Banks pay out to claimants or default and replacement.	
$t=2...$	Repeat steps as in $t=1$, but with 1b only if t is a multiple of N	

We consider two institutional frameworks: joint optimization and separate optimization. Under joint optimization welfare is maximized to the two policy tools:

$$\max_{r_t^f,\overline{d}_t} E\left[\sum_{t=1}^{T}\delta^{t-1}U_t\right] \tag{30}$$

We contrast this with a framework in which the monetary authority is given the task to smooth the stream of endowment income,

$$\min_{r_t^f}\sum_{t=1}^{T}\delta^{t-1}\left|\left[\lambda\left(r_t^f,\varepsilon_t\right)-\lambda\left(\widehat{r}^f,0\right)\right]\right| \tag{31}$$

while the regulator "cleans up" the incentive effects that the interest rate changes have on bank incentives using the leverage cap

$$\max_{\overline{d}_t} E\left[\sum_{t=1}^{T}\delta^{t-1}U_t\right] \tag{32}$$

where in (31) $\widehat{r}^f$ is the exogenous steady state (pre-shock) risk-free rate.

To be clear, we do not model any justification for why the monetary authority would focus only on smoothing endowment income. Within the context of the model it is quite obvious that nothing can improve over joint welfare maximization. However, we wish to use the model to analyze what it means for the dynamics of the policy rate when a monetary authority does not consider bank risk taking in its optimization. This is intended to capture the idea that traditionally the monetary authority focusses on shocks to its standard objectives and does not explicitly respond to bank incentives.

A key assumption implicit in the timing of the game is that after the shock at $t = 0$, the entire time path of r_t^f and $\overline{d}_t$ is announced by the policy makers, and that there is credible commitment to this path.[7] In principle, there would be scope for time inconsistency problems in our framework. After announcing a path for policy rates that locks banks into long term profiles with relatively little risk, the monetary authority could deviate and purely smooth the endowment shock. Implicitly, we are assuming the presence of some reputational costs of deviating. An explicit form of modelling to deal with time inconsistency would be a repeated game of the Tit-for-Tat type in which an authority's deviation from an announced path leads to a worse equilibrium in future repetitions. An alternative way to overcome the time inconsistency problem in our setting would be to have bank-firm relations start at different points in time. If, say, each period a constant fraction of banks can reoptimize its firm choice, then each period the monetary authority faces the same trade-offs. It cannot lock in all banks and then deviate. We do not explore these possibilities here.

D Results

As the static game could not be analytically solved, neither can the dynamic game. However, as before, we can derive comparative statics. Without solving for d_{it}^* and k_{it}^*, we can derive from (28) how these variables respond to changes in the policy tools, and we can infer how this affects optimal policy in the two institutional frameworks. In particular, we are interested in the path of policy rates that a separately optimizing monetary authority sets and how

[7] In allowing the regulator to set a path for $\overline{d}_t$ we are also assuming that regulatory tools are flexible over time. In reality this is often not the case, as for instance capital requirements are rarely adjusted. However, results are not qualitatively affected by making this tool inflexible (constant $\overline{d}$ for all t).

this differs from the socially optimal path inherent in joint optimization. This is recorded in Proposition 6.

If the transmission of monetary policy is such that excessive risk taking falls in the policy rate (Proposition 2), then keeping a needed rate cut short is important. The reason is that by facing banks with a shorter rate cut, fewer of the banks that would have chosen the good profile under $\widehat{r}^f$ will find it profitable to now fund a bad type firm. After all, the bank relation to the firm is long term, and therefore the bank considers the interest rate environment over the entire horizon of this relationship. A monetary authority that purely smooths the endowment shock misses out on this effect on bank optimization, and would keep rates low for too long. As proven in Proposition 4, the effects that this misspecified monetary policy has on welfare through bank incentives cannot be completely corrected by the regulator, since both sides of its trade-off are affected.

The response to a positive endowment shock is exactly inverse. Here, it is socially optimal to make the rate hike more protracted than a separately optimizing monetary authority would do.

Proposition 6 *Given:*

I. Condition 1

II. The sufficient condition derived in Proposition 2

III. The condition defined in Proposition 3

In response to a negative shock, $\nu_0 < 0$, a separately optimizing monetary authority keeps rates low for longer than is socially optimal. The converse is true for a positive shock.

Proof. Taken together I) and II) mean that $\overline{\varphi}_t^h$ falls in r_t^f, while III) means that within u_t effects on $R(k_{it})$ dominate those on $(d_{it} + \overline{e})$. For any $t\prime$ which is a multiple of N banks' optimization is:

$$\max_{d_{it},k_{it}} E\left[\sum_{t'}^{t'+N} \delta^{t-t'} A_t \left[\max\left\{\frac{1}{4w_t}(d_{it}+\overline{e})R(k_{it}) - \frac{1}{\varphi_i} - d_{it}\left(\frac{1+r_t^f}{1-q_{it}(1-\beta)} - 1\right), 0\right\}\right]\right]$$

which depends on the path of interest rates r_t^f between t' and $t'+N$. This implies that the effect on $\overline{\varphi}_t^h$ depends on the path of r_t^f.

Consider first $\nu_0 < 0$. And consider as t' the first decision point of banks, $t = 1$. By $\frac{\partial\lambda\left(r_t^f,\varepsilon_t\right)}{\partial r_t^f} < 0$ smoothing endowment income requires a decrease in r_t^f. But by $\theta < 1$ we have that as t increases $\varepsilon_t \to 0$ and therefore $r_t^f \to \widehat{r}^f$. Thus, the separately optimizing monetary authority's rate path is an initial cut and subsequently a gradual increase back to $\widehat{r}^f$. By

Proposition 4 the effect of monetary policy on expected welfare cannot be neutralized by $\overline{d}_t$. Therefore, in joint optimization, $\left(r_t^f\right)^*$ will reflect its impact on welfare. A steeper of the ascent of r_t^f between t' and $t'+N$ reduces the number of banks that would switch to $k_i^*=b$ as a consequence of the initial rate cut: the rise in $\overline{\varphi}_t^h$ becomes smaller. Hence, problem (30) yields a faster return to $\widehat{r}^f$ of r_t^f than problem (31).

Next consider $\nu_0>0$. The solution to (31) now yields a path that involves an initial rate hike and subsequent gradual decrease to $\widehat{r}^f$. All above arguments can be inverted. Thus, socially optimal monetary policy from (30) involves a more protracted rate hike. ■

5 Policy implications

This paper essentially has three aims. To model a channel through which monetary policy affects banks' risk taking. To use that channel to provide a justification for why it may make sense for a monetary authority to "lean against the wind" even when there is regulation. And finally, to indicate how this changes the dynamic path of optimal monetary policy.

The policy implications are threefold. Firstly, if central banks indeed wish to "lean against the wind", they need to keep rate cuts short. The reason is that banks only adjust their long-term assets towards more risk if they foresee that the rate will be kept low for a long time. This is the opposite side of the standard argument that in order to positively influence investment a monetary authority needs to fix expectations that its rate cut applies to a long horizon (Woodford (2003)). An important nuance to our argument, especially in the current environment, is the zero lower bound for monetary policy. Consider figure 1 in the introduction. If the initial rate is close to zero the two paths become very similar. The type of setting to which we believe our argument is applicable is the response to the bursting of the technology bubble in the first years of the new millennium. Rates were cut steeply and kept low - but well above zero - for many years.

Secondly, a rate hike is most effective at preventing the buildup of bank risk if the level of debt among banks is still relatively low. The more debt banks hold, the larger the negative impact on their charter values of a rise in debt service costs. This countervails the otherwise risk reducing incentives of a rate hike. In that respect, the right timing for a rate hike is early on in the leverage cycle. Obviously, the practical difficulty here is identifying what constitutes the outset of a leverage boom.

Thirdly, the correlation between banks' returns matters for monetary policy. When banks are exposed to similar shocks, the likelihood of sharp downturns rises. This is all the more true if they choose volatile portfolios. Therefore, the importance of preventing such choices increases. Within the context of our model the rationale for preventing the largest negative shocks is decreasing returns to scale. But more generally one can also think of consumers who want to smooth consumption over time and therefore particularly dislike sharp downturns. Importantly, moreover, correlated negative outcomes are associated with systemic risk in the financial sector. When interlinkage between banks plays a key role, for instance through liquidity provision on the interbank market, the prevention of excessive risk taking may gain further prevalence, as the entire sector can collapse if too many banks are simultaneously hit by an external shock. Our paper has not modelled any social costs to bank failure, however.

Appendix: General Equilibrium

We here consider the wealth effects of the static macro model presented in section 3. We consider that the consumer has an endowment of size λ which he uses to hold bank equity, bank debt and to fund bank deposit insurance / bailouts, while the remainder is invested in a risk-free asset. Note that though there is a single consumer, we assume that he is "schizophrenic" in the sense that he plays different roles with himself. That is, the fraction of him that is shareholder wants banks to purely maximize profits, not considering how that affects the rest of him. As mentioned before, the model provides no internal reason - such as bank runs - for the existence of a bank safety net. In fact, the consumer here lowers his own welfare by the provision of that guarantee, because, even though any bailout funds are transferred back to himself, in his role as shareholder his incentives are perversely affected, leading to the possibility that banks choose to fund risky firms.

The consumer's budget consists of wages, total bank revenues and risk-free returns on the part of the endowment not invested in banks:

$$B = w + \int_i \left[\frac{1}{4w} \left(d_i + \overline{e} \right) R \left(k_i \right) - \frac{1}{\varphi_i} \right] di + \overline{\lambda} \left(1 + r^f \right)$$

where

$$\overline{\lambda} = \lambda - \int_i \left(d_i + \overline{e} \right) di$$

The consumer receives bank revenues rather than profits, since also the repayments (or losses) to creditors accrue to him. Note that any payout of deposit insurance or bailout is budget neutral.

As the consumer spends his entire budget on the good with $p = 1$, and his preferences are linear in it, we have

$$E\left[u\right] = E\left[B\right]$$

Moreover, the labor market equilibrium is unchanged compared to (18), replacing from which we obtain

$$E\left[u\right] = E\left[\frac{1}{2} \sqrt{\int_i R\left(k_i\right)\left(d_i + \overline{e}\right) di} + \frac{\int_i R\left(k_i\right)\left(d_i + \overline{e}\right) di}{2\sqrt{\int_i R\left(k_i\right)\left(d_i + \overline{e}\right) di}} - \int_i \frac{1}{\varphi_i} di + \overline{\lambda}\left(1 + r^f\right) \right]$$

which becomes

$$E\left[u\right]=E\left[\sqrt{\int_{i}R\left(k_{i}\right)\left(d_{i}+\overline{e}\right)di}-\int_{i}\frac{1}{\varphi_{i}}di+\overline{\lambda}\left(1+r^{f}\right)\right]$$

from which it follows that the fundamental trade-offs are unchanged with respect to the outcome in partial equilibrium (equation (19)). Namely, welfare falls if more banks fund risky firms, and rises in the credit supply of banks. Thus, the trade-off of the regulator - restricting leverage to limit risk taking incentives versus the loss in credit supply - is unaltered.

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