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**Working Paper**

## Excessive bank risk taking and monetary policy

ECB Working Paper, No. 1457

**Provided in Cooperation with:**

European Central Bank (ECB)

*Suggested Citation:* Agur, Itai; Demertzis, Maria (2012) : Excessive bank risk taking and monetary policy, ECB Working Paper, No. 1457, European Central Bank (ECB), Frankfurt a. M.

This Version is available at:

<https://hdl.handle.net/10419/153890>

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EUROPEAN CENTRAL BANK

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## WORKING PAPER SERIES

NO 1457 / AUGUST 2012

### EXCESSIVE BANK RISK TAKING AND MONETARY POLICY

Itai Agur and Maria Demertzis



In 2012 all ECB  
publications  
feature a motif  
taken from  
the €50 banknote.



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**MACROPRUDENTIAL  
RESEARCH NETWORK**

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## Macroprudential Research Network

This paper presents research conducted within the Macroprudential Research Network (MaRs). The network is composed of economists from the European System of Central Banks (ESCB), i.e. the 27 national central banks of the European Union (EU) and the European Central Bank. The objective of MaRs is to develop core conceptual frameworks, models and/or tools supporting macro-prudential supervision in the EU.

The research is carried out in three work streams:

- 1) Macro-financial models linking financial stability and the performance of the economy;
- 2) Early warning systems and systemic risk indicators;
- 3) Assessing contagion risks.

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## Acknowledgements

This paper has particularly benefited from the feedback of Gabriele Galati, Sweder van Wijnbergen, Luc Laeven, Enrico Perotti and Nicola Viegi. We would also like to thank Steven Ongena, Claudio Borio, Refet Gurkaynak, Markus Brunnermeier, Marvin Goodfriend, John Williams, Viral Acharya, Ester Faia, Xavier Freixas, Linda Goldberg, Lex Hoogduin, David Miles, Lars Svensson, Kasper Roszbach, Hans Degryse, Wolf Wagner, Andrew Hughes Hallett, Neeltje van Horen, Vincent Sterk, John Lewis, Andrew Filardo, Dam Lammertjan, Jose Berrospide and Olivier Pierrard for discussions, and audiences at the IMF, the BIS, the ECB, the Fed Board, the Boston Fed, the Bank of England, the Bank of Japan (IMES), the Bank of Korea, the Hong Kong Monetary Authority / BIS Office HK, DNB, the 2010 CEPR-EBC Conference, the 2010 EEA, the 2010 MMF, the 2010 Euroframe Conference, and the 2011 SMYE for their comments. All remaining errors are our own. The views expressed in this paper do not necessarily reflect the views of the IMF or DNB. This paper has previously circulated as "Monetary Policy and Excessive Bank Risk Taking" and "Leverage, Bank Risk Taking and the Role of Monetary Policy".

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ISSN 1725-2806 (online)

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## **Abstract**

Why should monetary policy "lean against the wind"? Can't bank regulation perform its task alone? We model banks that choose both asset volatility and leverage, and identify how monetary policy transmits to bank risk. Subsequently, we introduce a regulator whose tool is a risk-based capital requirement. We derive from welfare that the regulator trades off bank risk and credit supply, and show that monetary policy affects both sides of this trade-off. Hence, regulation cannot neutralize the policy rate's impact, and monetary policy matters for financial stability. An extension shows how the commonality of bank exposures affects monetary transmission.

Keywords: Macprudential, Leverage, Supervision, Monetary transmission

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

## **Non-technical summary**

Should monetary policy target financial stability? A growing body of empirical research shows that interest rates affect the risk appetite of banks, although this by itself does not yet justify changing the mandate of a central bank. After all, there is also a bank regulator, whose task is specifically geared towards limiting bank risk. Cannot the bank regulator alone take care of bank risk, and undo any effects that the central bank's interest rates have on banks' risk profiles?

In this paper we model a banking sector and a bank regulator, and we analyze how they are affected by interest rates. Our primary result is that a bank regulator is not in the position to neutralize the impact that monetary policy has on bank risk incentives. The reason is that a bank regulator cares not just about preventing bank defaults, but also about having a healthy flow of financial intermediation. The regulator's task is to safeguard the financial system, which includes retaining financial stability as well as sufficient provision of credit. Monetary policy affects both financial stability and credit growth, both sides of a regulator's trade-off, which means that the regulator cannot reverse the effects of interest rates on the financial system. Therefore, there is a case to be made for coordinating bank regulation and monetary policy, instead of setting each separately.

Our paper is quite detailed in its modelling of the banking sector, but not of the macroeconomy. It thus differs from most of the literature on macro-financial interactions, where the macroeconomy is modelled in detail, while the banking sector usually is not. In our model banks take decisions about both sides of their balance sheet, that is, both about their asset risk and about the composition of their liabilities. In particular, they choose between a safe and a risky investment and they choose how much leverage to take on. A bank's decision problem then involves non-linearities and feedback effects: higher leverage makes a riskier profile more attractive because if things go wrong society bears more of the cost (through bailouts), while similarly a riskier profile also makes higher leverage more attractive. It is these type of non-linearities that have proven very difficult to integrate into standard macro models, but that can be analyzed within a banking model.

We identify three channels through which interest rates affect bank risk taking:

- The first is a substitution effect: when interest rates rise, the instruments with which banks lever up - mostly short-term wholesale funding in the pre-crisis years - become more expensive, so that banks want to lever less. Since banks' incentives to lever and to take on asset risk are complementary, this also lowers risk taking.
- A higher cost of banks' funding instruments lowers their profitability, which raises their incentive to take risk (they have less at stake) and thus goes against the substitution effect.
- However, a rate hike also makes the least efficient, riskiest banks exit the market.

The bank regulator can counteract banks' risk taking incentives by using a risk-based capital requirement. However, the higher the capital requirement the more banks constrain their credit provision to borrowers. A change in interest rates alters the entire "possibilities frontier" of a regulator, which means that no matter what it does, it cannot undo the impact of a change in interest rates. From the perspective of a society's welfare, the best thing the regulator can do is to only partly counteract the effects of interest rates. Thus, the presence of a bank regulator lessens the impact of monetary policy on bank risk, but does not eliminate it. We also show that when banks' exposures are more correlated, interest rates have an even bigger impact on financial stability.

Our paper relates to the causes of the recent crisis through its finding that periods of low interest rates are associated with greater financial imbalances. It also shows how bank leverage relates to monetary policy, which can help in fostering an understanding of the causes of leverage cycles.

# 1 Introduction

The financial crisis has reignited the debate on whether monetary policy should target financial stability. Those who favor a policy of leaning against the buildup of financial imbalances (Borio and White, 2004; Borio and Zhu, In press; Adrian and Shin 2008, 2009, 2010a,b; Disyatat, 2010), find their argument strengthened by a growing body of empirical research, which shows that the policy rate significantly affects bank risk taking.<sup>1</sup> But the opponents contend that, even if this is so, it is not clear that it justifies an altered mandate for the monetary authority: why cannot the bank regulator alone take care of bank risk? Is there really a need to use the blunt tool of monetary policy to achieve several targets (Svensson, 2009)? To analyze this question we model the transmission from monetary policy to bank risk, and its interaction with regulation.

In this paper we model banks that choose both how much leverage to take on and what type of assets to invest in. Banks are risk neutral and can choose between two types of projects. The "excessive risk" project has a lower expected return *and* a higher volatility than the "good" project. But limited liability creates an option value, which makes banks like volatility. The banks differ in their cost efficiency: the most efficient banks have high charter values, which means that their options are deep in-the-money, and they prefer the good profile. Less efficient banks instead attach greater value to volatility and choose the bad profile, while the least efficient exit. We define excessive risk taking in the banking sector as the share of active banks that select the bad profile.

The comparative statics of this excessive risk taking to the policy interest rate identifies what is commonly referred to as the risk-taking channel of monetary transmission (Borio and Zhu, In press). We find that this transmission channel consists of three types of effects. The first is a substitution effect: when the policy rate rises, the instruments with which banks lever up - mostly short-term wholesale funding in the pre-crisis years - become more expensive, so that banks want to lever less.<sup>2</sup> Moreover, banks' incentives to lever and to take on asset risk are complementary, because a more

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<sup>1</sup>This is found by Jiménez et al. (2009), Ioannidou, Ongena and Peydro (2009), Maddaloni and Peydro (2011), Altunbas, Gambacorta and Marquez-Ibanez (2010), Dell'Ariccia, Laeven and Marquez (2010), Buch, Eickmeier and Prieto (2010), Delis and Brissimis (2010), Delis and Kouretas (2011) and Delis, Hasan and Mylonidis (2011).

<sup>2</sup>The economic significance of this substitution effect is confirmed in the empirical work on monetary policy and leverage of Adrian and Shin (2008, 2009, 2010a,b), Angeloni, Faia and Lo Duca (2010) and Dell'Ariccia, Laeven and Marquez (2010).

levered bank has less to lose from risky loans. Thus, through this effect raising rates lowers risk taking. The second and third effects run through bank profitability. Increasing the cost of banks' funding instruments lowers their charter values, which raises their incentive to take risk and thus goes against the substitution effect. However, a rate hike also makes the least efficient, riskiest banks close their doors.

Overall, we show that a rate hike reduces excessive risk taking when banks' incentives to lever are moderate. In particular, moral hazard due to deposit insurance makes monetary policy less effective at reducing excessive risk. To the extent that recent bailouts have enlarged the sense of implicit guarantee among wholesale financiers, the crisis may have made monetary policy less able to affect financial stability in the future.

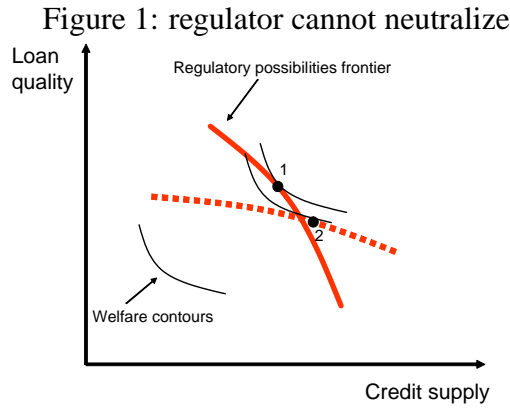
That ability of monetary policy to influence the financial sector only matters if the bank regulator cannot optimally perform its task alone. We derive from welfare the objective of a regulator by turning banks' abstract projects into labor-employing firms, whose wages flow to a representative consumer. Banks choose between two types of firms to fund, where risky firms have a higher volatility of productivity than safe firms. This volatility is harmful to consumers because firms have concave production functions, and variance reduces average output. Yet, those banks that internalize little of the downside risk, prefer funding risky firms. There is now a trade-off to bank leveraging: leverage raises banks' incentives to fund risky firms; but it also makes them raise credit supply, which causes firm expansion and benefits consumers.

A risk-based capital requirement can resolve this trade-off, as 100% equity financing for loans to risky firms ensures that no bank chooses a risky profile, while leveraging (and thereby supplying credit) against a safe portfolio is unrestricted. But this only works if the regulator possesses perfect information. We instead assume that he receives an imprecise signal on whether a bank funds a safe or a risky firm. The optimal risk-based capital requirement is now interior, because the regulator does not want to inadvertently restrain the credit supply of good profile banks too severely.

We analyze how changes in monetary policy affect the regulator's optimization. The policy rate impacts upon both sides of the regulator's trade-off, credit supply and excessive risk taking. This is why the regulator, although optimally adjusting capital requirements, cannot neutralize the



risk taking channel of monetary transmission. A way to see this is through a possibilities frontier, depicted in figure 1. A change in the policy rate alters the regulators' possibilities frontier from the solid to the broken line. This moves the regulator's welfare maximizing decision from point 1 to point 2. But in this example point 2 involves a lower welfare than point 1. Point 1 is no longer attainable for the regulator, however.



Finally, we consider an extension to common bank exposures. These common exposures come about by introducing positive correlation between firms' productivity draws, which initially were assumed to be independent. We show that the importance of monetary transmission rises in banks' correlation. The reason is that correlation creates the possibility of a joint negative productivity realization, which becomes more likely when banks have funded risky firms. The importance of combined regulatory and monetary policy to prevent such bank choices then rises.

The current paper focusses on a one-period framework. In a companion paper, Agur and Demertzis (2011), we take as given the "why to lean against the wind" analyzed in the current paper, and instead consider "how to lean against the wind", analyzing how the timing of optimal monetary policy changes when the monetary authority places weight on a financial stability objective. In response to a negative demand shock, this objective is shown to make rate cuts both deeper and shorter-lived, as the monetary authority aims to mitigate the buildup of bank risk caused by protracted low rates.

The next section discusses the related literature. Section 3 presents the bank model. Section 4 introduces an optimizing regulator and considers its interaction with the policy rate. Section 5 works

out the extension to correlated returns. Finally, section 6 discusses policy implications. All proofs are in the appendix.

## 2 Literature

Our banking model encompasses transmission effects identified in two recent papers. De Nicolò (2010) models the extensive margin: in his game, inefficient and risky banks are more likely to exit if the policy rate is high. Dell’Ariccia, Laeven and Marquez (2010) model effects through delevering and charter values.<sup>3</sup> In addition, a rate hike passes on to loan rates, which makes banks want to monitor more. These authors model a representative bank that chooses over a continuum of risk profiles (monitoring effort levels). We, instead, have a continuum of heterogeneous banks that choose between two risk profiles, which allows us to derive a definition of excessive risk in the financial sector. This, in turn, facilitates the connection to the welfare analysis that underlies the introduction of an optimizing regulator, whose interaction with monetary transmission we investigate. In addition, heterogeneity makes it possible to analyze the effects of correlation among banks.

A different way to consider monetary transmission is through the informational effects of rate changes. Drees, Eckwert and Várdy (2011) find that lowering interest rates raises investors’ portfolio share of opaque investments, because of Bayesian updating with noisy signals. Dubecq, Mojon and Ragot (2010) show that if investors overestimate bank capitalization then a rate cut amplifies their underpricing of bank risk. And, in a game between imperfectly informed banks, Dell’Ariccia and Marquez (2006) provide a mechanism in which a rate cut reduces the sustainability of the separating equilibrium wherein banks screen borrowers. Finally, Acharya and Naqvi (forthcoming) introduce an agency consideration into the analysis of monetary transmission: bank loan officers are compensated on the basis of generated loan volume. This causes an asset bubble, which a monetary authority can prevent by "leaning against liquidity".<sup>4</sup>

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<sup>3</sup>See Valencia (2011) for a type of reverse charter value effect. In Dell’Ariccia, Laeven and Marquez (2010) and our paper lower rates raise charter values, which makes banks internalize more of the risk they take. But in Valencia’s paper a rate cut only increases the upside of banks’ returns, making them take on more risk.

<sup>4</sup>See also Loisel, Pommeret and Portier (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.

On the macro side there have recently been many papers that build on the framework of Bernanke, Gertler and Gilchrist (1999) by incorporating 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.<sup>5</sup> Exceptions to this are Angeloni and Faia (2009), Angeloni, Faia and Lo Duca (2010) and Gertler and Karadi (2011) who construct macro models with banks that decide upon riskiness. However, all risk taking occurs on the liability side of banks. Instead, in Cociuba, Shukayev and Ueberfeldt (2011) banks choose between risky and safe investments, while leverage is given.<sup>6</sup> The interaction between leverage and asset risk choice cannot currently be incorporated into these models, because limited liability (or option structures more generally) introduces a kink in the optimization which cannot be linearized.

Finally, in addition to the ex-ante risk incentives that we focus on, one could also analyze the optimality of using interest rates as an ex-post bailout mechanism (Diamond and Rajan, 2008; Farhi and Tirole, forthcoming). 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, Rosengren and Tootell, 1999; Ioannidou, 2005).

### 3 Bank model

We assume a continuum of banks of measure 1. Each bank can choose from two types of projects: the "good" project,  $g$ , and the "bad" project,  $b$ . Here, the good project offers both a higher mean return and a lower volatility:

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

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In the policy debate "leaning against the wind" relates to the more general argument that in the years leading up to the crisis rates were kept low for too long. For discussions on this see Borio and Zhu (In press), Dell'Ariccia, Igan and Laeven (2008), Calomiris (2009), Brunnermeier (2009), Brunnermeier et al. (2009), Taylor (2009), Allen, Babus and Carletti (2009), Adrian and Shin (2010a), Diamond and Rajan (2009) and Kannan, Rabanal and Scott (2009).

<sup>5</sup>That is to say, banks do not choose a risk profile, nor can they default and make use of their limited liability. Nonetheless, also within this modelling approach the interaction between monetary policy and bank regulation can be investigated, as shown by De Walque, Pierrard and Rouabah (2010) and Darracq Pariès, Kok Sørensen and Rodriguez-Palenzuela (2011). Bank capital passes onto loan rates, and thus interacts with monetary transmission.

<sup>6</sup>This model is based on the argument made by Rajan (2006) that policy rates increase risk taking incentives by causing a search-for-yield.

and

$$\sigma_g < \sigma_b. \quad (2)$$

It is through this setup that we identify the meaning of excessive risk taking in our model. Though a risk-neutral investor would always prefer the good project, banks are different because of their limited liability, which makes their shareholders the owners of a call option. When returns are high they repay debtholders and still reap much for themselves, while when returns are low they can choose to default. Assuming that bank management represents risk-neutral shareholders, banks like volatile returns, therefore. From the perspective of a risk neutral bank the trade-off is between the benefit of the good project's higher return and the cost of its smaller volatility. In the current setup no bank would choose the good project if it offered equal expected returns. In section 4, when we make the projects into output-producing units, we show that the model can also work with the more familiar notation of a mean-preserving spread, as long as the production function is subject to decreasing returns to scale.

Our setup implies that we do not consider competition between banks (projects are bank specific) and that banks do not take a lending rate decision. The projects embody the banks' choice of the volatility of their portfolios: riskier loans have market values that fluctuate more strongly.

### 3.1 Bank return

Bank  $i$ 's distribution of gross returns,  $R > 1$ , is:

$$\omega(R|k_i, \varphi_i), \quad (3)$$

which is conditional on  $k_i \in \{g, b\}$ , the project choice, and on  $\varphi_i$ , the bank's efficiency parameter. The latter can be thought of as a bank's cost efficiency in handling a project, and is drawn from the distribution of banks' efficiency,  $\gamma(\varphi)$ . This distribution is assumed to be sufficiently wide, in a sense to be defined below (Lemma 2). A larger  $\varphi_i$  unambiguously improves a bank's return

distribution, in a first-order stochastic dominance sense: for  $\varphi_1 < \varphi_2$  and for any  $s > 1$

$$\int_1^s \omega(R|k_i, \varphi_1) dR > \int_1^s \omega(R|k_i, \varphi_2) dR, \quad (4)$$

Furthermore, project choice,  $k_i$ , affects the return distribution in the manner given by (1) and (2), which means that

$$\int_1^\infty R\omega(R|g, \varphi_i) dR > \int_1^\infty R\omega(R|b, \varphi_i) dR, \quad (5)$$

and by second-order stochastic dominance for any  $s > 1$

$$\int_1^s \Omega(R|b, \varphi_i) dR > \int_1^s \Omega(R|g, \varphi_i) dR, \quad (6)$$

where  $\Omega(R|k_i, \varphi_i)$  is the cumulative distribution function.

### 3.2 Leverage

On the liability side banks have a fixed amount of internal equity,  $\bar{e}$ , which can be from retentions of past earnings or inside equity of bank owners (we do not differentiate between owners and managers). Unlike external funds, internal funds are not attracted on the basis of an expected rate of return. Rather, internal equity holders accrue the residual returns of the bank. The issuance of additional external equity is assumed to be too costly. This type of structure, a reduced form departure from the Modigliani-Miller world with irrelevant capital structure, is used elsewhere in the banking literature.<sup>7</sup> The suboptimality of external equity finance can also be justified within the model, however, since debt is subsidized by partial deposit insurance (discussed below), and as we do not model bankruptcy costs this implies that debt is unambiguously a cheaper form of external financing.

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

$$x_i = \bar{e} + d_i. \quad (7)$$

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<sup>7</sup>See Thakor (1996) and Acharya, Mehran and Thakor (2010)

Bank debt is held by risk-neutral investors who are active on a perfectly competitive (and perfectly informed) financial market, and who cannot undertake projects by themselves (Diamond, 1984). Their claims are partly secured by an externally financed guarantee,<sup>8</sup> such that 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  $\beta \neq 0$ .<sup>9</sup>

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:

$$\begin{aligned} (1 - q_i) (1 + r_i^d) + q_i \beta (1 + r_i^d) &= 1 + r^f \\ r_i^d &= \frac{1 + r^f}{1 - q_i (1 - \beta)} - 1, \end{aligned} \quad (8)$$

where  $q_i$  is the probability that bank  $i$  will default:

$$q_i = \Pr [x_i R - d_i (1 + r_i^d) < 0], \quad (9)$$

and  $x_i R - d_i (1 + r_i^d)$  is bank  $i$ 's revenues minus what it must repay debtholders.

### 3.3 Bank maximization

Bank management maximizes profits with respect to its two decision variables:  $k_i$  (the project choice) and  $d_i$  (leverage):

$$\max_{k_i, d_i} \left\{ E \left[ \max \left\{ x_i R - d_i (1 + r_i^d), 0 \right\} \right] \right\}. \quad (10)$$

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<sup>8</sup>For the existence of which the model provides no justification.

<sup>9</sup>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.

Replacing from (7) and (8) we rewrite the problem as:

$$\max_{k_i, d_i} \left\{ E \left[ \max \left\{ (d_i + \bar{e}) R - d_i \left( \frac{1 + r^f}{1 - q_i (1 - \beta)} \right), 0 \right\} \right] \right\}, \quad (11)$$

given

$$q_i = \Pr \left[ (d_i + \bar{e}) R < d_i \left( \frac{1 + r^f}{1 - q_i (1 - \beta)} \right) \right]. \quad (12)$$

This problem cannot be solved analytically, because the max operator for profits is a kinked function, which is not differentiable. Moreover,  $q_i$  is a function of itself and would have to be solved numerically. We can prove that an interior solution exists, however:

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

Moreover, even though we have no analytical solution, we can derive properties on the type of project that a bank optimally chooses,  $k_i^*$ , in relation to its efficiency.

**Definition 1**  $\varphi_i = \bar{\varphi}^l$  *is the bank that is indifferent between inactivity or activity with  $k_i = b$ .*

**Definition 2**  $\varphi_i = \bar{\varphi}^h$  *is the bank that is indifferent between the two projects,  $k_i = b$  and  $k_i = g$ .*

**Lemma 2** *Banks choose their asset profile according to their efficiency:*

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

Lemma 2 shows that the least efficient banks ( $\varphi_i < \bar{\varphi}^l$ ) leave the market, banks with intermediate efficiency ( $\varphi_i \in (\bar{\varphi}^l, \bar{\varphi}^h)$ ) choose the bad project,  $k_i^* = b$ , and the most efficient banks ( $\varphi_i > \bar{\varphi}^h$ ) choose the good project,  $k_i^* = g$ . Intuitively, volatility is valuable to banks because potential default is not fully internalized in credit risk premia due to the safety net. But the more efficient and profitable banks are, the less likely default becomes, and hence the less valuable volatility. We can also explain this in terms of option valuation, where the option's "underlying asset" is the bank's

cash flow and the "strike price" is the point of default: the option is only exercised if it is "in the money", that is, if the value of the underlying asset exceeds the strike price (a call option). The value of volatility to option owners is generated by the fact that they gain on the upside but are insured on the downside. Efficient banks have options that are deep in-the-money, and owning an option that is very likely to be exercised is almost the same as owning a stock - owners care about both the upside and the downside - so that volatility loses its value. The benefit of the bad project is its larger volatility and this benefit thus becomes smaller for more efficient banks, so that the higher unconditional returns of the good project dominate their considerations.<sup>10</sup>

We use Lemma 2 to define excessive risk taking:

**Definition 3** *Excessive risk taking in the banking sector is the share of active banks that chooses the bad project:*

$$\frac{\int_{\bar{\varphi}^l}^{\bar{\varphi}^h} \gamma(\varphi) d\varphi}{\int_{\bar{\varphi}^l}^{\infty} \gamma(\varphi) d\varphi}. \quad (13)$$

Intuitively, this measure increases with  $\bar{\varphi}^h$  because fewer banks select the good project. And it declines in  $\bar{\varphi}^l$  as the exit of inefficient banks decreases the share of active banks with the bad project.

On banks' liability side there is no separation like there is on banks' asset side. Calling  $d_i^*$  a bank's optimal debt level, we have:

**Lemma 3**  $\exists d_i^* \in [0, \infty)$ . However,  $\frac{\partial d_i^*}{\partial \varphi_i}$  is not generally monotonic. The only unambiguous property is that at  $\bar{\varphi}^h$  we have  $\left. \frac{\partial d_i^*}{\partial \varphi_i} \right|_{\varphi_i = \bar{\varphi}^h} > 0$ .

The reason for the absence of a monotonic relation here is that, though more efficient banks have a lower marginal cost to taking on more debt, they could also have a lower marginal benefit. The lower marginal cost simply follows from the fact that financiers charge them lower funding rates. The marginal benefit is instead composed of two aspects: on the one hand, the mean return on projects is higher for more efficient banks, and so doing more of them, by leveraging, is more valuable; on the other hand, the effect that leverage has on variance is of greatest value to inefficient banks.

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<sup>10</sup>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).



This can again be seen through option valuation, because the value of volatility is greater when the underlying asset is close to the strike price. Since less efficient banks are those who are closer to default, this benefit of leveraging - which raises the variance of profits - falls in efficiency. Thus, we cannot prove a general monotonic relation between bank efficiency,  $\varphi_i$ , and optimal leverage,  $d_i^*$ . Unlike the relation between  $k_i^*$  and  $\varphi_i$  on the asset side, however, we do not require a clear-cut relation between efficiency and leverage for our results.

### 3.4 Monetary policy

The monetary policy rate - such as the Federal funds rate in the US or the repo rate in the eurozone - affects the cost of short-term wholesale bank funding directly. In the context of the model, we identify the policy rate with the risk-free rate  $r^f$  and use it to perform comparative statics. These statics identify what is commonly referred to as the risk-taking channel of monetary transmission (Borio and Zhu, In press), which in the context of our model is formalized as the impact of  $r^f$  on excessive risk taking as defined by (13).

**Proposition 1** *Monetary policy affects excessive risk taking through four effects:*

1. *the cost of debt funding (directly)*
2. *the cost of debt funding (indirectly) through credit risk premia*
3. *the optimal debt choice of the bank*
4. *by pushing banks into/out of activity.*

*For the first two effects it holds that  $\frac{\partial \bar{\varphi}^h}{\partial r^f} > 0$ . However, for the third effect it holds that  $\frac{\partial \bar{\varphi}^h}{\partial r^f} < 0$ . The overall sign of  $\frac{\partial \bar{\varphi}^h}{\partial r^f}$  is therefore ambiguous. The fourth effect implies that:  $\frac{\partial \bar{\varphi}^l}{\partial r^f} > 0$ .*

A bank's indebtedness and its incentive to take asset side risk are positively related, because a more levered bank, whose downside returns are more externalized, attaches greater value to a volatile asset portfolio. The key question is thus how monetary policy impacts upon a bank's debt burden. As Proposition 1 shows, the answer is threefold. First, there is a direct price effect. Following an

interest rate increase, the opportunity cost of holding bank debt increases and therefore bank funding becomes more expensive. Second, as funding costs rise, the probability that a bank will be able to repay its obligations declines. Default becomes more likely, and the risk premium that debtholders demand on bank debt increases. But, third, 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, and therefore also their incentive to take asset risk, is ambiguous. Finally, when rates rise banks become less profitable 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 effect.

Together these four effects constitute the risk-taking channel of monetary policy. The crucial question is therefore under which condition a rate hike will translate into less bank risk taking, as found by the empirical literature cited in the introduction.

**Proposition 2** *A sufficient condition for excessive risk (as defined by (13)) to fall in the policy rate is that for threshold bank  $i$  with  $\varphi_i = \bar{\varphi}^h$ :*

$$\left| \frac{\partial d_i^*}{\partial r^f} \right| > d_i^* \left[ \frac{1}{1 + r^f} + \frac{1 - \beta}{1 - q_i(1 - \beta)} \frac{\partial q_i}{\partial r^f} \right]. \quad (14)$$

This result is based on a hypothetical derivative. That is,  $d_i^*$  is known to exist (Lemma 3) and we consider its derivative to  $r^f$  even if we do not have a closed form solution for  $d_i^*$ . The sufficient condition that Proposition 2 derives, shows that the effect of a rate cut on risk taking depends on the optimal level of debt,  $d_i^*$ . When the threshold bank  $\bar{\varphi}^h$  is heavily levered, a rate hike strongly reduces its charter value. The more its charter value drops, the greater the bank's incentive to take risk, because it internalizes less of it: the likelihood that society pays for its risk taking increases. How highly the threshold bank is levered is itself an endogenous decision. Hence, it depends on the deeper parameters of the model whether the condition of Proposition 2 holds.

**Corollary 1 (to Proposition 2)** *If condition (14) holds for some  $\beta \in (0, 1)$  then: there exists a  $\bar{\beta}$  such that if  $\beta < \bar{\beta}$  then condition (14) holds while for  $\beta \geq \bar{\beta}$  it does not.*

Tighter monetary policy will only reduce excessive risk taking when  $\beta$  - the extent of deposit insurance - is small enough. Large deposit insurance for retail depositors or implicit guarantees for wholesale financiers thus serve to limit the ability of a rate hike to prevent risk buildup in the financial sector. Moral hazard interacts - or more precisely, interferes - with the effectiveness of monetary policy. Intuitively, with greater moral hazard, *ceteris paribus*, bank leverage is higher, and therefore the price effects (effects 1 and 2 in Proposition 1) gain importance.<sup>11</sup>

## 4 Regulation

Having considered how monetary policy impacts upon excessive bank risk taking in our model, we now work towards analyzing the interaction with regulation. We first identify the regulator's objective, then we define its tool, and finally we analyze how that tool interacts with the monetary policy rate.

### 4.1 The regulator's objective

To justify from welfare the objective of the regulator, we turn the previous section's abstract projects into productive units. We call these "firms", but we do not model them as borrowers with limited liability towards the banks - that is, banks are modelled as firm owners. The firms are simply the representation of the riskiness of the bank portfolio, just as the projects were before, but with the main difference that they employ labor. This allows us to relate the banks' asset choice to consumer welfare.

The output of firm type  $k$  financed by bank  $i$  is

$$y(k_i) = f(\alpha_i, (d_i + \bar{e}), l_i^d), \quad (15)$$

where  $l_i^d$  is the labor input,  $(d_i + \bar{e})$  is the capital input (which is the funding received from the bank) and  $\alpha_i$  is the technological efficiency parameter of the firm. Instead of banks drawing a return, now

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<sup>11</sup>Note that we cannot state the reverse, i.e., that tighter monetary policy will increase excessive risk taking when  $\beta$  is large enough. Proposition 2 derives a sufficient, but not necessary condition.

firms draw their technological efficiency, which determines their profitability. At given firm profits,  $\Pi_i$ , bank returns are a deterministic function:  $R(\Pi_i, \varphi_i)$ . Thus, there are two levels of efficiency, namely firm efficiency at producing output,  $\alpha_i$ , which is stochastic, and bank efficiency,  $\varphi_i$ , which is given. Bank efficiency can be thought of as the cost of monitoring the firm, or it could be a general overhead cost of operating the bank.

Just as we had good and bad projects before, there are now good and bad firm types, determined by the volatility of their output efficiency. A firm's efficiency parameter is drawn from the distribution  $\lambda(\alpha_i | k_i)$ , where  $\lambda(\alpha_i | b)$  is a mean preserving spread over  $\lambda(\alpha_i | g)$ : bad type firms have a higher variance of productive efficiency than good type firms, but their distributions have the same mean. Recall from the introduction that this is essentially the relaxation of an assumption. That is, in the previous section we assumed that bad projects have both a higher volatility and a lower mean return. We could assume the same for bad firms and all results below would hold. But instead, we can go one step further and let go of the assumption that bad firms have lower mean returns, retaining only the difference in volatility; the difference in average expected returns will arise endogenously here due to decreasing returns to scale, as explained below.

Formally, by the definition of second order stochastic dominance

$$\begin{aligned} \int_0^\infty \alpha_i \lambda(\alpha_i | b) d\alpha_i &= \int_0^\infty \alpha_i \lambda(\alpha_i | g) d\alpha_i, \\ \int_0^s \Lambda(\alpha_i | b) d\alpha_i &> \int_0^s \Lambda(\alpha_i | g) d\alpha_i, \end{aligned}$$

for any  $s > 0$ , and where  $\Lambda(\alpha_i | k_i)$  is the cumulative distribution function. We initially assume that firm efficiency draws are independent,  $E[\alpha_i | \alpha_j] = E[\alpha_i]$ , an assumption that is relaxed in section 5.

All firms produce the same homogeneous good, and they do so with a decreasing returns to scale technology:  $\frac{\partial f(\cdot)}{\partial j} > 0$  and  $\frac{\partial^2 f(\cdot)}{\partial j^2} < 0$  for all  $j = d_i, l_i^d, \alpha_i$ . Due to decreasing returns to scale there can be heterogeneous efficiency firms that all operate profitably in a single good market. Moreover, decreasing returns to scale imply that in selecting a firm type to finance, banks face the same type of trade-off as in the previous section. Bad type firms offer a higher volatility of returns, which

is of value to banks because of the option value induced by limited liability. But with a concave production function higher volatility translates into lower output on average. Thus, through the same mechanism as before, the most efficient banks prefer funding safe firms, while less efficient banks attach greater value to volatility and fund risky firms.

The firm's profit is given by

$$\Pi_i = p [f(\alpha_i, (d_i + \bar{e}), l_i^d)] - w l_i^d, \quad (16)$$

where  $p$  is the price of the good and  $w$  is the market wage rate. As there is only one good, its price functions as numeraire, and can be normalized to  $p = 1$ .

There is a risk neutral representative consumer with a fixed, inelastic labor supply,  $\bar{l}^s$ . His utility increases monotonically in the market wage rate,  $w$ , since he spends his entire income on one good only. We focus on partial equilibrium in our analysis, in the sense that we abstract from wealth effects through bank profits, and thus take  $w$  as our measure of welfare. We can derive comparative statics to the wage rate from the labor market equilibrium. From the first order condition of firm profits to  $l_i^d$ , a firm's labor demand is given by

$$(l_i^d)^* = \arg \max_{l_i^d} [f(\alpha_i, (d_i + \bar{e}), l_i^d) - w l_i^d], \quad (17)$$

so that total labor demand can be expressed as

$$\int_i (l_i^d)^* di = \int_i \arg \max_{l_i^d} [f(\alpha_i, (d_i + \bar{e}), l_i^d) - w l_i^d] di. \quad (18)$$

Hence, the labor market equilibrium is given by

$$\int_i \arg \max_{l_i^d} [f(\alpha_i, (d_i + \bar{e}), l_i^d) - w l_i^d] di = \bar{l}^s, \quad (19)$$

and the market wage rate is the  $w$  for which this equation holds.

**Lemma 4** *At given firm type choices,  $k_i$ , a weak increase in the bank leverage of all banks ( $d_i$  rises*

for some banks while it does not fall for others) raises the market wage rate,  $w$ .

**Lemma 5** *When a larger share of banks takes on excessive risk ( $\bar{\varphi}^h$  rises), welfare declines:  $\frac{\partial w}{\partial \bar{\varphi}^h} < 0$ .*

Recall that the market wage rate is equivalent to consumer welfare here, because - as we abstract from wealth effects - labor income is the sole determinant of consumption, and consumption (of the single good) is all the consumer cares about. These results then mean that welfare rises in banks' credit supply, while it falls in the extent that they take excessive risk. Intuitively, the consumer likes bank credit supply, because it expands firm size, which raises labor demand and thereby wages. And he dislikes excessive risk taking because when funds are channeled to riskier firms, productive efficiency becomes more volatile, which lowers labor demand on average, due to decreasing returns to scale.

Credit supply and risk taking are connected through bank leverage. The more leverage banks take on, the more credit they supply, but simultaneously the greater their incentives to fund risky firms. This trade-off underlies the problem of the regulator, whose objective is to maximize  $w$ .

## 4.2 The regulator's tool

If the regulator were to possess perfect information, its optimization problem would be trivialized. It could simply require banks to hold 100% capital if they choose to fund a bad type firm. Then, no bank would choose to do so, since it would fully internalize its downside returns.

However, we assume the presence of asymmetric information, in that the regulator receives an imprecise signal on the asset choice of a given bank. With probability  $\pi \in (\frac{1}{2}, 1)$  he observes the true firm type that the bank is funding, but with probability  $(1 - \pi)$  his signal is false. The timing of the game is:

Table 1: the timing of the game

1. Regulator sets correspondence of capital requirement to observed risk
2. Banks choose firm type (of which regulator observes a signal)
3. Banks set leverage subject to implied capital requirement
4. Firm efficiencies realized (independent draws)

In this game the regulator's tool is a risk-based capital requirement, which is a correspondence between the observed risk taking of a bank and the minimum fraction of equity in total liabilities (as in the various Basel accords). The regulator determines this correspondence at the beginning of the game. Banks then function subject to the imposed regulatory environment. At stage 2 they choose the firm type they wish to finance,  $k_i$ , of which the regulator observes  $\tilde{k}_i$ . Thus, for instance, if  $\tilde{k}_i = b$  then  $k_i = b$  with probability  $\pi$  (signal correct) and  $k_i = g$  with probability  $(1 - \pi)$  (signal incorrect). The capital requirement is the maximum amount of leverage that a bank is allowed to set given  $\tilde{k}_i$ :  $\bar{d}(\tilde{k}_i)$ . Since the amount of equity is fixed,  $\bar{e}$ , a cap on leverage effectively determines how much capital a bank must hold as a fraction of its total liabilities.<sup>12</sup>

The regulator now faces the following trade-off. On the one hand, if it sets a tough capital requirement (a low  $\bar{d}(b)$ ) then it will incentivize banks to choose to fund a good type firm. As long as  $\bar{d}(b) < \bar{d}(g)$  banks that choose  $k_i = b$  face a higher probability to have their capital restricted than those that choose  $k_i = g$  (since  $\pi > \frac{1}{2}$ ). And the greater is the difference between  $\bar{d}(b)$  and  $\bar{d}(g)$  the larger the punishment on banks that choose  $k_i = b$ . On the other hand, the regulator knows that its signal is imperfect, and that some good banks will inadvertently see their capital bounded, which lowers credit supply without improving risk taking. Using statistical terminology, the choice of an optimal capital requirement involves weighing type I and type II errors: the risk that good-profile banks will be restricted versus the risk that bad-profile banks will get away with their socially detrimental behavior.

Intuitively, this can be thought of in terms of the risk weights that regulators put on different types of asset classes. Assigning risk weights to asset classes is a key part of the Basel Accords. But regulators do not know the true risks associated with the different asset classes, while banks are

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<sup>12</sup>We thus abstract from the issue that banks sometimes opt to hold capital *above* the regulatory requirement (Zhu, 2008): here the requirement always binds.

diverse in their exposures to the classes. If the risk-weight placed on a given asset class is too high then some banks, which actually may be relatively good, will be forced to delever. But if the weights on some class are too low, then those banks that invest relatively heavily in them and are actually quite risky, will get away.

Define  $\bar{d}^* (\tilde{k}_i)$  as the optimal risk-based capital requirement. Then:

**Lemma 6** *There exists a  $\bar{\pi}$  such that for  $\pi < \bar{\pi}$  we have that  $\bar{d}^* (\tilde{k}_i)$  is interior:  $\bar{d}^* (b) > 0$ .*

Lemma 6 shows that when the regulator's signal is sufficiently imprecise, there will be an interior solution, in that the regulator does not impose 100% capital requirements when observing high risk taking.

Note that we do not prove that an interior solution exists for  $\bar{d}^* (g)$ , which would mean that  $\bar{d}^* (g) < \max_i d_i$ : it is always optimal to restrict the leverage of at least some of the banks of which the regulator receives the signal that they are funding good firms. The reason that this cannot be proven relates to the fact that there is no monotonic relationship between efficiency and optimal leverage (Lemma 3). Non-monotonicity implies that the regulator may or may not need to constrain the credit supply of many good-profile banks before capturing some of the bad-profile banks that were incorrectly classified as good. However, we do not require proving that an interior solution exists for  $\bar{d}^* (g)$ . An interior solution for  $\bar{d}^* (b)$  is sufficient to prove our result on the interaction with monetary policy.

### 4.3 Bank regulation and monetary policy

**Proposition 3**  $\frac{\partial w}{\partial r^f} \neq 0$ : *optimal regulation,  $\bar{d}^* (\tilde{k}_i)$ , cannot neutralize the risk-taking channel of monetary policy. That is, the effects that the policy rate,  $r^f$ , has on bank decisions do affect welfare, even in the presence of an optimizing regulator.*

Monetary policy affects loan quality as well as credit supply. Unless capital requirements and the policy rate affect both of these variables identically - and they do not - then the regulator cannot neutralize the impact that a change in monetary policy has. Here we are giving the regulator the



maximum extent of "flexibility" to cope with bank risk taking. In reality, capital requirements and the risk weights of various asset classes are only infrequently adjusted, contrary to monetary policy which moves much more frequently. But even giving the regulator the greatest degree of policy flexibility does not suffice to counterbalance the risk-taking channel of monetary policy.

## 5 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  $\rho$  denote the correlation coefficient of efficiency draws  $\alpha_i$ .

**Proposition 4** *Greater correlation between banks' returns raises the impact of monetary policy on welfare:  $\frac{\partial}{\partial \rho} \left( \left| \frac{\partial w}{\partial r^T} \right| \right) > 0$ .*

Proposition 4 shows that the impact of monetary policy on welfare increases in  $\rho$ . The reason is that decreasing returns to scale make welfare decline in variability: with a concave production function mean output falls in variance. Thus, correlated negative efficiency draws are particularly bad for welfare. The greater is correlation, the more important the task at hand for policy makers to reduce volatility in bank portfolios. And since, as seen in Proposition 3, regulation cannot do the job on its own, the potential for monetary policy to affect welfare through the risk-taking channel rises in the commonality of bank exposures.

## 6 Policy implications

In modelling the risk-taking channel of monetary transmission, and showing that regulation cannot neutralize it, our theory has focussed on providing an argument for why to "lean against the wind". But it also has some implications for how to do so. 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 profitability of a rise in debt service costs, which 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.

The effectiveness of monetary policy in combatting excessive risk cannot be seen separately from regulatory design, moreover. Banks' moral hazard dampens the ability to contain the buildup of risk, as it amplifies their leveraging incentives. Hence, addressing moral hazard may be key for retaining "leaning against the wind" as a policy option. Moreover, the correlation between banks' assets matters for the impact of monetary policy, which implies that regulations aimed at containing common exposures in the financial system interact with monetary transmission.

## Appendix: Proofs

**Proof of Lemma 1.** The solution to equation (12) 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 ( $\Pr[\cdot]$ ) is positive. But it also cannot happen at  $q_i = 1$  as then the right-hand side is smaller than one. Therefore,  $q_i \in (0, 1)$ . ■

**Proof of Lemma 2.** We first consider the case of threshold  $\bar{\varphi}^h$ . 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  $z \rightarrow \infty$  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 (11)

$$z = (d_i + \bar{e})R - d_i \left( \frac{1 + r^f}{1 - q_i(1 - \beta)} \right), \quad (20)$$

where in expectation  $R$  is increasing in  $\varphi_i$  (equation (4)). And, as can be seen in (12)  $q_i$  falls in  $\varphi_i$ , which implies that  $\frac{1+r^f}{1-q_i(1-\beta)}$  falls and therefore  $z$  increases. Hence,  $z$  is monotonically increasing in  $\varphi_i$ . 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  $\bar{\varphi}^h$  banks will choose  $k_i^* = g$ .

The existence of  $\bar{\varphi}^l$  is straightforward: by (4) when efficiency is so low that, in expectation,  $x_i R$  does not cover  $d_i(1 + r_i^d)$  then operating the bank yields negative expected return, and it is closed down. ■

**Proof of Lemma 3.** We first prove the second and third sentences of the Lemma under the assumption that  $\exists d_i^*$ , and subsequently prove this existence. Concerning  $\frac{\partial d_i^*}{\partial \varphi_i}$ , more efficient banks have smaller cost to more leverage, as follows from  $\frac{\partial q_i}{\partial \varphi_i} < 0$  in (12) and  $\frac{\partial}{\partial q_i} \left( \frac{1+r^f}{1-q_i(1-\beta)} \right) > 0$  in (11). The

relation of  $\varphi_i$  to the marginal benefit of leverage is ambiguous, however. On the one hand, in (11)  $E[R]$  is higher for larger  $\varphi_i$ , and thus the derivative  $\frac{\partial}{\partial d_i} (d_i + \bar{e}) E[R]$  rises. On the other hand, a larger  $d_i$  raises the variance of  $\max\{z, 0\}$  where  $z$  is as given by (20). From option valuation theory (Hull, 2002) we know that the marginal benefit of additional volatility is largest around the strike price, and then declines in the value of the underlying asset. As  $z$  rises in  $\varphi_i$ , the value of that additional volatility (higher  $d_i$ ) is greater for less efficient banks, closer to the default point. If both the marginal cost and the marginal benefit of leverage decline in  $\varphi_i$ , then whether more efficient banks take on more or less debt is ambiguous.

However, at  $\bar{\varphi}^h$  we know that  $q_i$  makes a discrete jump. Thus, the marginal cost of debt falls discretely, whereas the marginal benefit (value of volatility) if it declines at all in  $\varphi_i$ , declines continuously. Hence, at  $\bar{\varphi}^h$  it must be that  $\frac{\partial d_i^*}{\partial \varphi_i} > 0$ .

Finally,  $\exists d_i^* \in [0, \infty)$  by the fact that in (11) the marginal cost of debt is rising,  $\frac{\partial}{\partial d_i} \left( \frac{1+r^f}{1-q_i(1-\beta)} \right) > 0$  as  $\frac{\partial q_i}{\partial d_i} > 0$ , while instead the marginal benefit of debt falls in  $d_i$ . The latter is true because  $\frac{\partial}{\partial d_i} (d_i + \bar{e}) E[R]$  is constant in  $d_i$ , while the positive value of the additional variance induced in  $\max\{z, 0\}$  decreases by the same argument as above:  $z$  moves away further from the strike price. ■

**Proof of Proposition 1.** Effects 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. Effect 1: the numerator rises. Effect 2: the denominator falls, because  $q_i$  in equation (12) increases when  $r^f$  increases. Following the argument in the proof of Lemma 2, 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 (20). Therefore, banks will require a higher efficiency  $\varphi_i$  to be willing to take up the good project. This means that the threshold  $\bar{\varphi}^h$  rises: among active banks, more banks select the bad project. Effect 3 follows from the fact that

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

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 effect  $d_i \frac{1+r^f}{1-q_i(1-\beta)}$  falls in equation (20), and by the inverse of the argument above this means that  $\bar{\varphi}^h$  declines: a larger fraction of active banks chooses the good project. Finally,  $\frac{\partial \bar{\varphi}^h}{\partial r^f} > 0$

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  $\bar{\varphi}^l$  rises. This is the fourth effect. ■

**Proof of Proposition 2.** Though  $d_i^*$  cannot be analytically derived, Lemma 3 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

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

where  $\frac{\partial q_i}{\partial r^f} > 0$ . This can be rewritten to

$$\frac{\partial d_i^*}{\partial r^f} < -d_i^* \left[ \frac{1}{1 + r^f} + \frac{1 - \beta}{1 - q_i(1 - \beta)} \frac{\partial q_i}{\partial r^f} \right],$$

and given that  $\frac{\partial d_i^*}{\partial r^f} < 0$ , this can be written to the form stated in the proposition.

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

$$\frac{\partial}{\partial r^f} \left[ \frac{\int_{\bar{\varphi}^l}^{\bar{\varphi}^h} \gamma(\varphi) d\varphi}{\int_{\bar{\varphi}^l}^{\infty} \gamma(\varphi) d\varphi} \right] < 0.$$

■

**Proof of Corollary to Proposition 2.** For  $\beta \rightarrow 1$  we have that  $d_i^* \rightarrow \infty$ . But  $\frac{\partial d_i^*}{\partial r^f} \nrightarrow -\infty$ . In fact,  $\lim_{\beta \rightarrow 1} \frac{\partial d_i^*}{\partial r^f} = 0$  because if

$$E[R] > 1 + r^f,$$

then a bank takes on infinite debt. This holds until  $r^f$  is so high that the above condition is reversed, at which point the bank shuts down (and the derivative is undefined). This implies that condition (14) cannot hold for  $\beta \rightarrow 1$ . But since condition (14) holds for some  $\beta \in (0, 1)$  then there must exist

a  $\bar{\beta} < 1$  beyond which it no longer holds. ■

**Proof of Lemma 4.** This follows from  $\frac{\partial f(\cdot)}{\partial d_i} > 0$  in conjunction with equation (19): if  $d_i$  rises for some banks without falling for any then the left-hand side of equation (19) increases. Since  $w$  is the variable that makes the equation hold, and since the left-hand side falls in  $w$ , it must be that  $w$  rises. ■

**Proof of Lemma 5.** When  $\bar{\varphi}^h$  rises then  $\alpha_i$  becomes more volatile for some firms, while it does not become less volatile for any. By  $\frac{\partial^2 f(\cdot)}{\partial \alpha_i^2} < 0$  this means that  $f(\cdot)$  in equation (19) falls. By the same argument as in the proof of Lemma 4 this means that  $w$  decreases. ■

**Proof of Lemma 6.** Consider the two extremes:  $\pi \rightarrow 1$  and  $\pi \rightarrow \frac{1}{2}$ . First we show that for  $\pi \rightarrow 1$  the optimal policy is  $\bar{d}^*(b) = 0$  and  $\bar{d}^*(g) \rightarrow \infty$ . Under this policy,  $k_i = g \forall i$  at stage 2, since banks know that  $k_i = b$  always implies  $\bar{d} = 0$ , under which all of the downside of the bad type firm is internalized, so that  $E[y(g)] > E[y(b)]$  (by  $\frac{\partial^2 f(\cdot)}{\partial \alpha_i^2} < 0$ ) unambiguously dominates. Since,  $\bar{d}^*(b) = 0$  and  $\bar{d}^*(g) \rightarrow \infty$  now achieves  $\bar{\varphi}^h = \bar{\varphi}^l$  (no excessive risk taking), while credit supply is unrestricted, it cannot be improved upon (by Lemmas 4 and 5) and is thus optimal.

Instead, for  $\pi \rightarrow \frac{1}{2}$  it cannot be that  $\bar{d}^*(b) = 0$ . Since the regulator's signal is entirely uninformative,  $\bar{d}^*(b) = 0 \Rightarrow \bar{d}^*(g) = 0 \Rightarrow d_i = 0 \forall i$ . That is, credit supply is maximally constrained. But this cannot be the optimum, because marginally increasing  $\bar{d}(b)$  by  $\varepsilon$  leads to a discrete gain in credit supply but no loss in bank risk. The reason is that for each given bank debt constitutes a fraction  $\frac{\varepsilon}{\bar{e} + \varepsilon} \rightarrow 0$  of liabilities, and hence downside risk of bad type firms is still fully internalized. But integrating over a continuum of banks the marginal increase implies a discrete gain in credit supply. With  $\bar{d}^*(b) = 0$  for  $\pi \rightarrow 1$  and  $\bar{d}^*(b) > 0$  for  $\pi \rightarrow \frac{1}{2}$  it follows that there is a  $\bar{\pi} \in (\frac{1}{2}, 1)$  such that for  $\pi < \bar{\pi}$  we have that  $\bar{d}^*(b) > 0$ , while for  $\pi > \bar{\pi}$  the converse is true. ■

**Proof of Proposition 3.** By Lemma 6 we can distinguish two cases:  $\pi < \bar{\pi}$  and  $\pi \geq \bar{\pi}$ . First consider  $\pi \geq \bar{\pi}$ , with associated corner solution  $\bar{d}^*(b) = 0$ . Take a bank that in the absence of regulation would have  $k_i^* = b$ . Under regulation its expected cost of choosing such a profile is that with probability  $\pi$  it is forced to hold 100% capital ( $d_i = 0$ ). This does not depend upon

$r^f$ . However, the expected benefit of the profile, namely being able to implement  $k_i = b$  without restrictions on leverage (with probability  $1 - \pi$ ), is affected by  $r^f$ . If the condition in Proposition 2 holds, then for a lower  $r^f$  the profitability to the bank of  $k_i = b$  with unrestricted leverage rises (and vice versa if the condition does not hold). With constant expected cost and changing expected benefit, it follows that  $r^f$  affects  $\bar{\varphi}^h$  and thereby  $w$  (Lemma 5).

Now consider  $\pi < \bar{\pi}$  with interior solution  $\bar{d}^*(b) > 0$ . At stage 2 the bank maximizes to the firm-type choice ( $k_i$ ), by backward induction over stages 3 and 4. The choice is: set  $k_i = b$  or  $k_i = g$ . If  $k_i = b$  then expected profits are

$$\pi E \left[ \max \left\{ \left( \min \left\{ d_i^*, \bar{d}^*(b) \right\} + \bar{e} \right) R(\Pi_i, \varphi_i) - \min \left\{ d_i^*, \bar{d}^*(b) \right\} \left( \frac{1 + r^f}{1 - q_i(1 - \beta)} \right), 0 \right\} \right] + \\ (1 - \pi) E \left[ \max \left\{ \left( \min \left\{ d_i^*, \bar{d}^*(g) \right\} + \bar{e} \right) R(\Pi_i, \varphi_i) - \min \left\{ d_i^*, \bar{d}^*(g) \right\} \left( \frac{1 + r^f}{1 - q_i(1 - \beta)} \right), 0 \right\} \right]$$

And if  $k_i = g$  then expected profits are

$$(1 - \pi) E \left[ \max \left\{ \left( \min \left\{ d_i^*, \bar{d}^*(b) \right\} + \bar{e} \right) R(\Pi_i, \varphi_i) - \min \left\{ d_i^*, \bar{d}^*(b) \right\} \left( \frac{1 + r^f}{1 - q_i(1 - \beta)} \right), 0 \right\} \right] \\ + \pi E \left[ \max \left\{ \left( \min \left\{ d_i^*, \bar{d}^*(g) \right\} + \bar{e} \right) R(\Pi_i, \varphi_i) - \min \left\{ d_i^*, \bar{d}^*(g) \right\} \left( \frac{1 + r^f}{1 - q_i(1 - \beta)} \right), 0 \right\} \right]$$

Here,  $r^f$  and  $\bar{d}^*(b)$  enter differently into the equations: the derivatives towards them are unequal. When two policy tools have unequal derivatives, then they can not "neutralize" each other. Any change in  $r^f$  will affect  $w$ , therefore, no matter how  $\bar{d}(\tilde{k}_i)$  is adjusted. ■

**Proof of Proposition 4.** With independent draws and a continuum of banks, we have that  $\hat{\alpha} = E[a_i]$ , where  $\hat{\alpha}$  is the mean technological efficiency. It is then the dispersion around that mean, which by  $\frac{\partial^2 f(\cdot)}{\partial(\alpha_i)^2} < 0$  reduces  $E[f(\cdot)]$  and thereby  $w$  (Lemma 5). But with correlated returns  $\hat{\alpha}$  is not constant: the larger is  $\rho$ , the greater the variance of  $\hat{\alpha}$ . By  $\frac{\partial^2 f(\cdot)}{\partial(\alpha_i)^2} < 0$  and  $\int_0^s \Lambda(\alpha_i|b) d\alpha_i > \int_0^s \Lambda(\alpha_i|g) d\alpha_i$  we then have that  $\left| \frac{\partial w}{\partial \bar{\varphi}^h} \right|$  increases in  $\rho$ . Since  $\frac{\partial \bar{\varphi}^h}{\partial r^f}$  does not depend on  $\rho$  it follows that  $\left| \frac{\partial w}{\partial \bar{\varphi}^h} \frac{\partial \bar{\varphi}^h}{\partial r^f} \right|$  increases in  $\rho$ . ■

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