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Bank Size and Risk-Taking under Basel II†

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Abstract: We analyze the relationship between bank size and risk-taking under the New Basel Capital Accord. Using a model with imperfect competition and moral hazard, we show that the introduction of an internal ratings based (IRB) approach improves upon flat capital requirements if the approach is applied uniformly across banks and if the costs of implementation are not too high. However, the banks' *right to choose* between the standardized and the IRB approaches under Basel II gives larger banks a competitive advantage and, due to fiercer competition, pushes smaller banks to take higher risks. This may even lead to higher aggregate risk-taking.

Keywords: Basel II, IRB approach, bank competition, capital requirements, SME financing.

JEL-Classification: G21, G28, L11.

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1 Introduction

Although not yet implemented, the Basel II Accord has come under fire by both academics and politicians. The critique by academics centers on the inability of the accord to control aggregate risk because it neglects the endogeneity of risk and tends to have procyclical effects (see, e. g., Daníelsson, Embrechts, Goodhart, Keating, Muennich, Renault, and Shin (2001)). In contrast, politicians are worried about the potential consequences of the new accord for the provision of credit, most notably to small- and medium-sized enterprises (SMEs). This has even led to an amendment of the accord, which now has special provisions for loans to SMEs.

Our paper describes a novel channel through which the new capital regulation (Pillar I of the new Basel Accord) may harm especially small banks—and hence their borrowers, who tend to be small as well— and thereby lead to an increase in aggregate risk. Interestingly, this result does not follow from the implementation of the internal ratings based (IRB) approach as such, but rather from the banks' *right to choose* between the standardized and the IRB approaches. In fact, in our model, the introduction of an IRB approach can be beneficial to small banks if it is applied uniformly to all banks and the fixed costs of implementation are small.

The problem arises from the implicit asymmetric treatment of small and large banks by the new regulation: The implementation of the IRB approach requires large initial investments in risk management technologies, which may deter small banks from choosing the IRB approach. Then only large banks profit from the reduction in capital requirements (and hence marginal costs) for safe loans in the IRB approach. This gives them a competitive advantage over small banks. In our model, this may lead to reduced market shares and higher risk-taking at the small banks, due to fiercer competition in the market for deposits, and to an increase in aggregate risk in the economy. If small banks are specialized in extending loans to small firms, the shrinking market shares of small banks implies a cutback in the lending to these borrowers, especially to the more creditworthy ones among them.[1]

There is by now a large literature on the new Basel Accord. Most empirical papers (too many to be reviewed here) deal with the question whether the accord assigns the correct risk weights to different risk groups. We will abstract from this issue here by assuming that the risk weight functions are "correct." Several papers deal with the adverse macroeconomic effects of Basel II, especially with its procyclicality and its neglect of the endogeneity of financial risk (see, e. g., Lowe (2002), Kashyap and Stein (2004), and Daníelsson, Shin, and Zigrand (2004)). Similar to the authors of those papers, we are interested in the implications of the new accord for the aggregate risk in the economy (but in a static setup). A paper by Decamps, Rochet,

[1]It is now widely accepted that small banks have a competitive advantage in extending relationship loans based on soft information to opaque borrowers (who tend to be small), whereas large banks have an advantage in granting loans based on hard information to transparent borrowers. See Berger and Udell (2002) and Stein (2002) for theoretical arguments, and Haynes, Ou, and Berney (1999), Berger, Miller, Petersen, Rajan, and Stein (2002), Cole, Goldberg, and White (2004), and Carter and McNulty (2005) for empirical evidence using U. S. data.

and Roger (2004) is the only one to analyze the interactions among the three pillars of the new accord. In contrast, we focus on pillar I, the new capital regulation.

The papers most closely related to ours are those by Rime (2003) and Repullo and Suarez (2004), in which the implications of the co-existence of the standardized and the IRB approaches for banks' risk choices are analyzed. Both papers argue that banks eligible for the IRB approach have a competitive advantage in the provision of low-risk loans (because the IRB approach has a lower capital requirement), while the less sophisticated banks have a competitive advantage in the provision of high-risk loans (because the standardized approach has a lower capital requirement). This leads to a sorting of borrowers: High risk borrowers tend to be financed by unsophisticated banks, and low risk borrowers by sophisticated banks.[2]

Our paper makes a different, and complementary, point by starting from a setup that differs in several important respects from those used by Rime, and Repullo and Suarez. First, there are no moral hazard effects in their models. Their results are entirely driven by the cost differentials from the two regulatory approaches. In our model, we emphasize moral hazard effects because we believe that one of the main purposes of capital requirements is to provide incentives for prudent bank behavior.[3] Second, the other two papers model bank competition in the loan market, and ignore competition on the liabilities side. In both models, it is crucial that borrowers are actually able to switch among banks. In contrast, we model competition on the liabilities side of banks' balance sheets, and ignore competition for loans by assuming that banks serve different clienteles in their loan business. The large empirical literature contrasting relationship and transactions loans, cited above, points to a strong segmentation in loan markets: Large banks specialize in different types of loans than smaller banks. In a context similar to ours, Berger (2004) presents empirical evidence for limited competition in loan markets among banks that are likely to adopt the IRB approach and other (smaller) banks. This suggests that it is appropriate to abstract from loan market competition for the case relevant in our model, namely the competition among large and small banks. We assume, however, that large and small banks draw from a similar pool of deposits. Finally, we also consider the effects of regulation on *aggregate* risk-taking in the economy.

In order to analyze the effect of the coexistence of the standardized and the IRB approaches under the new Basel Accord, we need a model of capital regulation as a reference point. This model has to be sufficiently simple to remain tractable even in the presence of an asymmetric banking sector, but it should also yield reasonable predictions of the effects of capital regulation. In a related paper, Repullo (2004) models the effects of flat and risk-based capital requirements. Our model assumptions are similar to those employed by Repullo, but there also are a number of

[2]Repullo and Suarez (2004) add an interesting quantitative analysis where they simulate the effects of Basel II on loan rates and quantify the social costs of bank failures needed to justify the actual IRB capital requirements.

[3]Most of the existing literature has focussed on moral hazard as the main motivation for capital requirements. Another prominent explanation is the role of capital as a buffer against losses. Finally, Morrison and White (2006) argue that capital requirements may help to prevent unsound banks from taking up operations, thereby solving an adverse selection problem.

differences: First, Repullo uses a dynamic framework to explicitly model franchise values. Second, deposits are fully insured in his model; as a result, deposit rates do not depend on the riskiness of investments. Third, Repullo focuses on symmetric equilibria, whereas we also analyze asymmetric outcomes. Finally, we explicitly model the disciplining effect of outside equity on inside equity holders; in contrast, Repullo considers only outside equity and assumes that the interests of the management and the outside equity holders are aligned. In spite of these differences, our model yields similar predictions on the effects of flat and risk-based capital requirements: Flat capital requirements can induce banks to invest prudently, but risk-based capital requirements can achieve the same result at lower capital costs. Moreover, in both models, risk-taking tends to increase as competition for deposits intensifies. The main focus of our paper is, however, on the coexistence of flat and risk-based capital requirements. This adds an interesting twist to the analysis.

Another related paper is by Berger (2004), who empirically assesses the competitive effects caused by the preferential treatment of SME loans in the IRB approach. Our theoretical idea could also be applied to this more specific issue because it also implies a difference in capital requirements (and hence marginal costs) across different bank groups. Note, however, that our main interest is in the asymmetric treatment of banks due to the right to choose between the standardized and the IRB approaches, which may be quantitatively much more important than the "carve-out" on SME loans. Consistent with our assumption above, Berger concludes that the competitive effects in the loan market are likely to be small because large and small banks tend to make different kinds of loans. However, our analysis suggests that considering the competitive effects on the loan market may not in itself make for a sufficient assessment of the implications of the special provisions for SME loans.

In the next section, we describe the features of the New Basel Capital Accord that are relevant for our theoretical model. Section 3 contains the setup of the model. In Section 4, we analyze a banking sector where all banks are regulated according to the standardized approach. Section 5 turns to the IRB approach. We first show what happens when all banks are required to adopt the internal ratings based approach. Then we analyze the situation where banks can choose between the standardized and the IRB approaches. Section 6 concludes.

2 The New Basel Capital Accord

Our analysis focuses on one particular—and arguably the most important—aspect of the new Basel Capital Accord: the enhancement of the risk sensitivity of capital requirements for credit risk.[4] Instead of sorting assets into broad risk categories as in the 1988 Basel Accord, the new accord envisions that capital requirements depend directly on the debtors' external or internal ratings. However, the information requirements are so high that only a subset of banks will be able to reliably provide

[4] A description of the accord can be found in Basel Committee on Banking Supervision (2004).

the necessary information. Therefore, the new accord offers banks two distinct options for calculating capital requirements for credit risk: a standardized approach and an internal ratings based (IRB) approach.[5] Within the IRB approach, banks can opt for a foundation or an advanced IRB approach, differing with respect to the extent that internal information is used.

As in the old accord, banks are required to have a capital ratio of at least 8 percent. The capital ratio is defined as the regulatory capital divided by risk-weighted assets. The modifications in the new accord mostly affect the definitions of risk weights in the denominator of the capital ratio. In the model, we will not distinguish between regulatory capital and equity. Also, instead of defining risk weights, we will use the effective capital requirements implied by such weights. For example, a risk weight of 75 percent translates into an effective capital requirement of 6 percent.

The *standardized approach* is very similar to the old Basel Accord. Assets are grouped into different supervisory categories, giving rise to different risk weights. In contrast to the old accord, the standardized approach recommends the use of external ratings, if they exist, and specifies different risk weights for different rating classes; in most other cases, the risk weight is 100 percent. In many countries, hardly any external ratings exist for a large part of corporate loans, especially to SMEs; hence, the 100 percent weight applies to them (as it did in the old accord).[6] Similarly, no external ratings exist for retail exposures; however, these loans are now subject to reduced risk weights of only 75 percent. In our model, we will assume that no external ratings are used under the standardized approach. This is similar to the simplified standardized approach (Basel Committee on Banking Supervision (2004, Annex 9)). Also, we will not distinguish between corporate and retail exposures. Hence, the minimum capital requirement is flat with regard to the riskiness of loans in our model. Because of the similarity of the standardized approach and the old regulation, we will treat them as identical.

In the *IRB approach*, risk weights depend directly on the external and internal assessments of asset risk. Banks estimate risk characteristics, such as the probability of default, on the basis of their internal data. These estimates then serve as inputs for the risk weight formulas specified by the Basel Committee. Retail exposures carry much smaller risk weights than corporate exposures. In our model, we define different capital requirements for different risk classes of assets, where the requirement for safe assets is below the flat requirement in the standardized approach and the requirement for risky assets is above it. This is in line with the objective of the Basel Committee to broadly maintain the aggregate level of minimum capital requirements (see Basel Committee on Banking Supervision (2004, paragraph 14)). It is not clear, however, whether this statement refers to the initial portfolio structure, or to that after portfolio adjustments in reaction to the new accord.

[5] A similar right to choose existed in the old Basel Accord regarding the treatment of market risk, where banks can choose between an internal models approach and a standardized method.

[6] An exception are the United States where many corporate borrowers are rated. However, the standardized approach is not going to be implemented in the U. S. Instead, the banks (other than the largest ones) will be allowed to stick to the old Basel Accord.

Both approaches contain special provisions with respect to SME lending: First, under certain conditions, loans to SMEs can be categorized as retail loans in both approaches, benefitting from smaller capital requirements. In addition, the IRB approach allows for a firm-size adjustment for exposures to SMEs. This also reduces capital requirements.[7] Hence, SME lending is especially favored in the IRB approach, which reinforces the asymmetric treatment of large and small banks in the new accord (see Berger (2004) for an empirical analysis of this issue).

Finally, the New Basel Accord contains a long list (51 paragraphs!) of minimum requirements that a bank has to fulfill to be eligible for the IRB approach. Therefore, the introduction of the IRB approach requires high fixed costs (e. g., for the installation of a sophisticated risk management system), which may deter smaller and less sophisticated banks from using the IRB approach. In addition, the lack of sufficient historical data may make the use of the IRB approach unfeasible for smaller banks. In neither case would small banks benefit from the decrease in capital requirements for relatively safe exposures. This paper analyzes how this asymmetric treatment of large and small banks affects banks' risk-taking and performance, as well as the aggregate risk in the economy. Note that our results do not hinge on the specific modelling details of the regulation. The main effect is driven by the combination of fixed costs and reduced marginal costs in the new regulation. Our specification is meant to model these features in the simplest way.[8]

3 Model Setup

Banks Consider an economy with $n+1$ chartered banks and without bank entry. The banks have limited liability and are risk neutral. They are owned by penniless bankers (the inside equity holders), whose only wealth is the bank charter. They collect deposits and outside equity, and can invest these funds in one risky project. There are thus three stakeholders at the bank: depositors, outside equity investors, and the banker (the inside equity investor).

Each bank can choose from two types of projects. The "safe" project yields y_1 with probability p_1 for each invested unit, and zero otherwise. The "risky" project yields y_2 with probability p_2, and zero otherwise. Assume that $p_1\, y_1 > p_2\, y_2 > 1$; then, due to risk neutrality, an investment in the safe project is efficient. Assume also that

[7] The illustration in the official documentation suggests that the firm-size adjustment reduces capital requirements by 20 to 25 percent.

[8] The exact implementation of the new Basel Accord may differ across jurisdictions. In Europe and Japan, the new accord will probably be applied to all banks in their jurisdictions. In the United States, however, the largest banks will be required to switch to the Advanced IRB approach, whereas all other banks may remain in the old Basel I regulation or switch to the Advanced IRB approach. Even in such a situation, our main argument remains valid unless the largest banks would have preferred to stick to Basel I.

$y_2 > y_1$, so that there is scope for the typical risk-shifting problem à la Stiglitz and Weiss (1981). The risk-taking of banks cannot be observed by the banks' investors.[9]

In the banking sector, there are n small banks (S) and one large bank (L). The large bank competes with all small banks for deposits, whereas the small banks compete only with the large bank, but not with other small banks (see the left panel of Figure 1). This is to capture the idea that small banks operate in isolated local markets where they compete with large banks maintaining a branch at the same location, but not with small banks from other locations. This market structure implies that each local market can be analyzed separately.

In the deposit market, there is imperfect competition à la Hotelling (1929). Each small bank is connected with the large bank by a linear road of length 1, where the small bank is located at position x_S of that road, and the large bank at position $x_L > x_S$. Moreover, we assume that $1 - x_L > x_S$, which implies that the large bank has a larger "backyard" than the small bank. Each road is inhabited by a uniformly distributed mass λ of risk neutral depositors who have a discount factor of one. Each depositor is endowed with one dollar. As an alternative to bank deposits, depositors have access to a storage technology. There is no deposit insurance.[10] Depositors incur non-monetary transportation costs, which are quadratic in the distance between the depositor and the bank, i. e., t multiplied by the quadratic distance. A depositor at position x who chooses the small bank at x_S is promised a nominal repayment of r_S^{nom}. If he anticipates that the bank is solvent with probability p_S, his expected payoff is $p_S\, r_S^{\text{nom}} - t\,(x - x_S)^2 = r_S - t\,(x - x_S)^2$, where $r_S = p_S\, r_S^{\text{nom}}$ is the expected repayment. Analogously, his expected payoff is $r_L - t\,(x_L - x)^2$ if he chooses the large bank at x_L. We assume that transportation costs are so small that the depositors' participation constraints are always satisfied. Then the depositor at position $\bar{x} = \frac{x_S + x_L}{2} + \frac{r_S - r_L}{2\,t\,(x_L - x_S)}$ is just indifferent between the two banks' offers. Given identical parameters for all small banks, we can concentrate on symmetric equilibria in which all small banks choose the same strategy. Then the deposit volumes of the small banks and the large bank are, respectively,

$$\begin{aligned} d_S &= \lambda\,\bar{x} = \lambda\,\frac{(x_S + x_L)}{2} + \frac{\lambda}{2\,t\,(x_L - x_S)}\,\big(r_S - r_L\big) \quad \text{and} \\ d_L &= n\,\lambda\,(1 - \bar{x}) = n\,\lambda\,\big(1 - \frac{x_S + x_L}{2}\big) + \frac{n\,\lambda}{2\,t\,(x_L - x_S)}\,\big(r_L - r_S\big). \end{aligned}$$

Combining terms, we can write

$$\begin{aligned} d_S &= D_S/n + \sigma\,(r_S - r_L) \quad \text{and} \\ d_L &= D_L + n\,\sigma\,(r_L - r_S). \end{aligned} \tag{1}$$

D_L and D_S/n can be interpreted as the banks' clienteles. If two competing banks set identical deposit rates, their deposit supplies are just those of their clienteles;

[9] Note that the "risky" project has a higher probability of default, but not necessarily a higher variance. Hence our assumptions do *not* imply that the projects can be ordered in the mean-variance-space. The project with the higher mean return may have a higher or lower variance.

[10] For our purpose, it would be sufficient to assume that deposits are not *completely* insured.

these are the banks' "backyards," plus one half of the area in-between. Because the large bank has a larger backyard than the small banks in every market, the clientele of the large bank is larger than the total clientele of the small banks, i. e., $D_L > D_S$. The parameter σ measures the substitutability of the banks' deposits from the viewpoint of the depositors. If σ is small (i. e., transportation costs and the distance between banks are large), depositors are reluctant to switch banks, even in the presence of relatively big differences in expected returns, and banks nearly enjoy monopolies with respect to their clienteles. If σ is large (i. e., transportation costs and the distance between banks are small), the deposit market is rather competitive; depositors are very sensitive to interest rates. The specification implies that the aggregate supply of deposits is completely inelastic and equal to $D_L + D_S = n\,\lambda$. Deposit rates determine only how the aggregate supply is distributed among banks; they do not affect the aggregate supply. This means that any amount of deposits gained by one bank must be lost by another.

Banks can also finance their projects through outside equity, k_j. Equity is provided by investors, who demand an exogenously given expected return of r_k, which can be interpreted as the opportunity cost of equity investors. Raising equity is "expensive," i. e., $r_k > p_1\,y_1$, and it therefore dilutes the value of a bank's inside equity.[11] Hence, equity finance would be inefficient in the absence of a moral hazard problem, but it can be used for mitigating the risk-shifting problem. We assume that depositors do not have access to the market for equity; this allows us to ignore the optimization problem of investors who can choose between holding deposits or bank equity.[12] We implicitly assume that the management holds some shares (inside equity) in the bank. This assumption is not crucial. What we need is that the management has some interest in their bank's profits (this could also be through stock option plans or other performance-based compensation schemes).

Capital Adequacy We analyze two different regulatory approaches.

1. The *standardized approach* does not distinguish between projects with different risk levels. A fraction of at least α of a bank's assets must be financed by equity. Hence, a bank's balance sheet must satisfy the regulatory constraint

$$k_j \geq \alpha\,(d_j + k_j),$$

   where $d_j + k_j$ is the amount invested in risky assets.

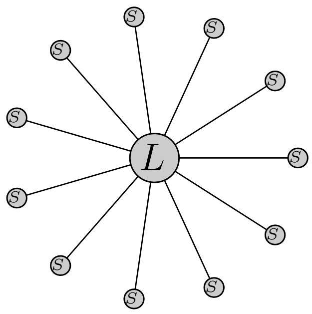
2. The *internal ratings based (IRB) approach* distinguishes between different risk classes. The regulatory constraint is

$$k_j \geq \beta_1\,(d_j + k_j) \tag{2}$$

[11]This assumption has become standard in the literature (see, e. g., Hellmann, Murdoch, and Stiglitz (2000) and Repullo (2004)). The classical justification for the dilution cost is a lemons problem, as in Myers and Majluf (1984) or Rock (1986).

[12]The dilution cost of outside equity can also be derived from general equilibrium considerations; see, for example, Gorton and Winton (2000) and Hellmann, Murdoch, and Stiglitz (2000).

Figure 1: Competitive Structure and Timeline



- Banks choose regulatory approaches.
- Banks announce deposit rates r_j and collect deposits d_j. Depositors anticipate banks' risk choices.
- Banks sell shares to get equity k_j. Shareholders anticipate banks' risk choices.
- Banks choose projects and invest.
- Projects mature. If the projects are successful, banks repay debt and equity; otherwise, they default and repay nothing.

The left panel illustrates the competitive structure in the banking sector; L refers to the large bank, S to the small banks. The right panel shows the timeline of our model.

if the bank chooses the safe project, and

$$k_j \geq \beta_2 \left(d_j + k_j\right) \tag{3}$$

if the bank chooses the risky project, where $\beta_2 > \alpha > \beta_1$. Finally, the IRB approach requires a sophisticated internal risk management, entailing a non-monetary fixed cost of C.

The above specification implicitly assumes that the regulator has some enforcement mechanism to make the banks comply with the regulation and truthfully report their risk-taking. Why, then, does the regulator not prohibit banks from taking risky projects? One possible explanation is that, in reality, risky projects are not necessarily inefficient; all that regulators want to prohibit is *excessive* risk-taking. Banks may be better than regulators in choosing the optimal risk-return ratio of their projects. Therefore, regulators should not ban risky projects completely, but instead put a disincentive on risk-taking, as has been described by Rochet (1992). The assumption of truthful reporting also underlies the Basel II regulation in reality. The fact that we do not observe a prohibition of risky projects suggests that the observed combination of regulatory rules, supervision, and disclosure are believed to be superior. An explicit model of this complicated dynamic interaction between banks and regulators is beyond the scope of this paper.

The right panel of Figure 1 displays the time structure of the model. We do not consider the stage where the regulator sets the regulatory parameters α, β_1, and β_2; these are taken as given by earlier regulatory decisions. Furthermore, we assume that banks collect deposits before equity.[13] This implies that banks cannot use their equity to signal project quality to depositors. If they could, there would be no need for regulation because banks would voluntarily choose a sufficient amount of

[13]Technically, this is similar to assuming that depositors are unable to observe their bank's equity; see Morrison and White (2006).

equity.[14] We will now characterize the equilibria of the model under different types of capital regulation.

4 The Standardized Approach

In this section, we assume that all banks *must* adopt the standardized approach.

4.1 Risk Choices of Banks

We determine the equilibrium by using backward induction. First, we study the banks' risk choices for given deposit volumes, deposit rates, and capital structures. Then we analyze the banks' behavior in the equity market, and finally (in Section 4.2) their behavior in the deposit market.

In this model, there is a simple decision rule concerning banks' project choices. A bank will choose the risky project if and only if expected returns on deposits exceed a critical deposit rate, r^{crit}. If a bank j collects d_j units of deposits and k_j units of equity, it can invest $d_j + k_j$ in risky assets. The index j will be omitted when there is no danger of confusion. Since equity cannot be used as a signal, regulatory constraints will always bind, $\alpha = k/(d+k)$ and $1-\alpha = d/(d+k)$.

If the bank chooses the safe project, its expected project returns are $p_1\, y_1\, (d+k)$. The expected debt service is $r\, d$, hence profits after debt service are $p_1\, y_1\, (d+k) - r\, d$. Assume that a fraction δ of profits is paid to outside equity investors; the banker receives the remaining profits, $(1-\delta)\,(p_1\, y_1\, (d+k) - r\, d)$. If the depositors expect the bank to choose the safe project, the profits accruing to the banker are

$$\Pi^1 = (1-\delta)\, p_1\, (y_1\, (d+k) - r\, d/p_1), \tag{4}$$

given that the bank chooses the safe project as anticipated by the depositors. If, however, depositors anticipate that the bank will choose the safe project and it opts for the risky project, expected profits are

$$\Pi^2 = (1-\delta)\, p_2\, (y_2\, (d+k) - r\, d/p_1).$$

The critical expected return that equalizes Π^1 and Π^2 is

$$r^{\text{crit}} = \frac{d+k}{d}\, p_1\, \frac{p_1\, y_1 - p_2\, y_2}{p_1 - p_2} = \frac{p_1}{p_1 - p_2}\, \frac{p_1\, y_1 - p_2\, y_2}{1-\alpha}. \tag{5}$$

[14]Our time structure captures the idea that, due to changing costs, depositors are "stuck" with their bank once they have deposited their funds there. If depositors could withdraw their funds without costs after observing the bank's equity (and inferring the bank's project choice), and deposit at another bank, they could punish their bank for misbehavior. We exclude this type of disciplining device.

Now look at the equity investors' decision problem. If the shareholders anticipate that the bank will take the safe project, the expected payment to them amounts to $\delta\,(p_1\,y_1\,(d+k) - r\,d)$. This must at least equal $r_k\,k$, otherwise equity investors do not participate. In equilibrium, the term will be equal to $r_k\,k$. Solving this equation for δ and substituting into (4), we get

$$\Pi^1 = (d+k)\,p_1\,y_1 - r\,d - k\,r_k.$$

Considering further that $k = d\,\alpha/(1-\alpha)$ implies

$$\Pi^1 = d\left(\frac{p_1\,y_1 - \alpha\,r_k}{1-\alpha} - r\right).$$

Following the same procedure for the risky project, and combining the two profit functions, we get expected profits of

$$\Pi = d\left(\frac{p_i\,y_i - \alpha\,r_k}{1-\alpha} - r\right), \tag{6}$$

with $i = 1$ (safe project) for $r \leq r^{\mathrm{crit}}$ and $i = 2$ (risky project) for $r > r^{\mathrm{crit}}$.

Capital adequacy has two effects on the profitability of banks. First, for a given project choice, it deteriorates profitability, because the bank is forced to refinance itself through expensive equity. In general, part (but not necessarily all) of this cost is going to be shifted to depositors in the form of reduced deposit rates. Second, a higher α increases the critical deposit rate r^{crit}. If this induces a bank to take the efficient project where it otherwise would have chosen the inefficient one, profitability is enhanced. Then the capital regulation is beneficial for the bank because it allows the bank to commit to the safe project and thus to avoid higher refinancing costs.

Our model of capital requirements differs from most of the existing literature in that it explicitly models the disciplining effect of *outside* equity for *inside* equity holders.[15] Issuing outside capital enables the bank to commit to choosing the safe project because it dilutes the bank's share in the risky project's repayment in case of success. Most of the literature considers either banks with owner-managers without any outside equity (examples are Repullo and Suarez (2004) and Morrison and White (2006)), or banks with only outside equity, where the managers are assumed to maximize the bank's profits (as in Hellmann, Murdoch, and Stiglitz (2000) and Repullo (2004)). The modelling approach closest to ours is by Acharya (2003).

4.2 Reaction Functions of Banks

After having discussed the banks' risk choices and the shareholders' investment decisions, let us finally come to the banks' behavior in the deposit market. We start with the analysis of a single bank (without loss of generality, the large bank) in a specific local market. If competition is weak and deposit rates are low, moral hazard

[15]We thank an anonymous referee for drawing our attention to this point.

is not a problem, and the large bank will choose the safe project. We will establish constraints on σ afterwards. Substituting (1) into (6) yields

$$\Pi_L^1 = \big(D_L + n\,\sigma\,(r_L - r_S)\big)\,\Big(\frac{p_1\,y_1 - \alpha\,r_k}{1-\alpha} - r_L\Big).$$

The first-order condition implies

$$r_L = \frac{1}{2}\,\Big(\frac{p_1\,y_1 - \alpha\,r_k}{1-\alpha} + r_S - \frac{D_L}{n\,\sigma}\Big). \tag{7}$$

The bank's expected profits are

$$\Pi_L^1 = \frac{n\,\sigma}{4}\,\Big(\frac{p_1\,y_1 - \alpha\,r_k}{1-\alpha} - r_S + \frac{D_L}{n\,\sigma}\Big)^2,$$

and its deposit volume is

$$d_L = \frac{n\,\sigma}{2}\,\frac{p_1\,y_1 - \alpha\,r_k}{1-\alpha} + \frac{D_L - n\,\sigma\,r_S}{2}.$$

When the competitor's rate r_S rises, the bank reacts by also offering higher rates (see (7)). At some point r_S^{kink}, it reaches the critical rate with $r_L = r^{\text{crit}}$,

$$r_S^{\text{kink}} = 2\,r^{\text{crit}} + \frac{D_L}{n\,\sigma} - \frac{p_1\,y_1 - \alpha\,r_k}{1-\alpha}.$$

When r_S rises further, the bank does not immediately offer higher deposit rates, but it continues to offer r^{crit} (hence the kinks in Figure 2). Otherwise, depositors would anticipate that the bank will choose the risky project and demand a higher default premium. The bank's deposit volume is now $d_L = D_L + n\,\sigma\,(r^{\text{crit}} - r_S)$.

However, at some point r_S^{jump}, market rates are so high that the bank prefers to raise its rate, thereby admitting that it will take the risky project, but "regaining" some volume. After this point, the bank sets a deposit rate of

$$r_L = \frac{1}{2}\Big(\frac{p_2\,y_2 - \alpha\,r_k}{1-\alpha} + r_S - \frac{D_L}{n\,\sigma}\Big).$$

The nominal rate is then r_L/p_2. The regime switch occurs when expected profits of the bank are equal in both regimes,

$$\big(D_L + n\,\sigma\,(r^{\text{crit}} - r_S)\big)\,\Big(\frac{p_1\,y_1 - \alpha\,r_k}{1-\alpha} - r^{\text{crit}}\Big) = \frac{n\,\sigma}{4}\,\Big(\frac{p_2\,y_2 - \alpha\,r_k}{1-\alpha} - r_S + \frac{D_L}{n\,\sigma}\Big)^2.$$

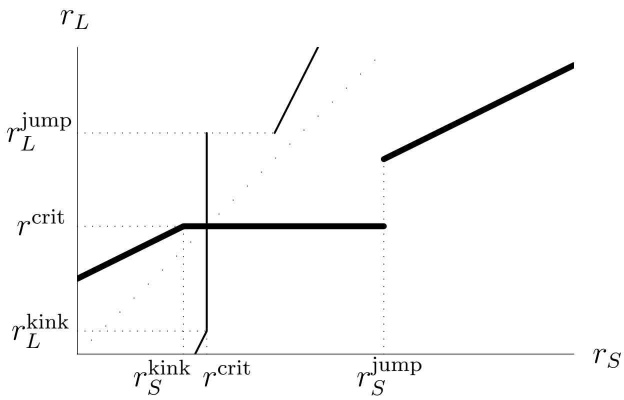
Such an increase in expected deposit rates is profitable for the bank, even though it reduces its margin (through the reduction in expected project returns and the increase in deposit rates). The reason is the accompanying gain in market share, which compensates for the lower profit margin. Hence, at the critical r_S^{jump}, the deposit volume of the bank jumps up.

Summing up, the large bank's reaction function is

$$r_L = \begin{cases} \frac{1}{2}\Big(\frac{p_1\,y_1 - \alpha\,r_k}{1-\alpha} + r_S - \frac{D_L}{n\,\sigma}\Big) & : \quad r_S \le r_S^{\text{kink}}, \\ r^{\text{crit}} & : \quad r_S^{\text{kink}} < r_S \le r_S^{\text{jump}}, \\ \frac{1}{2}\Big(\frac{p_2\,y_2 - \alpha\,r_k}{1-\alpha} + r_S - \frac{D_L}{n\,\sigma}\Big) & : \quad r_S^{\text{jump}} < r_S. \end{cases}$$

The reaction functions of the small banks have an analogous form. Figure 2 depicts the reaction functions of both bank types for a numerical example.

Figure 2: Reaction Functions



Here and in the following figures, the parameters are $y_1 = 2$, $p_1 = 2/3$, $y_2 = 3.5$, $p_2 = 1/3$, $\alpha = 1/10$, $r_k = 3/2$. Furthermore, $t = 20/9$, $x_S = 1/4$, $x_L = 11/20$, and $\lambda = 1$, implying that $D_L = 3/5$, $D_S = 2/5$, and $\sigma = 3/4$. The thick curve is the reaction function of the large bank, the thin curve is that of small banks.

4.3 Equilibrium

The equilibrium lies at the intersection of the reaction functions. Given the geometric structure of those functions, there is at least one equilibrium. However, the intersection may not be unique. For example, all banks may take the safe project (with deposit rates below the jump) in one equilibrium, whereas they may all take the risky project (with deposit rates above the jump) in another equilibrium. In such cases, we pick the Pareto-superior equilibrium with the lower deposit rates.[16]

Banks' behavior can be characterized by a number of regimes, differing with respect to the banks' risk-taking and deposit rates. The regime in which the banks find themselves depends on the intensity of competition. In our discussion, we start from a regime with low competition (small σ), and then consider what happens if σ is increased. Figure 3 illustrates the effects of competition on banks' deposit rates, volumes, profits, and on welfare. We first discuss banks' deposit rates and risk-taking, before turning to banks' profits and to welfare.

Regime 1: All banks below the kink When both types of banks are below the kink, moral hazard is not a problem, and all banks choose the safe project. Equilibrium deposit rates are

$$\begin{aligned} r_L &= \frac{p_1\, y_1 - \alpha\, r_k}{1-\alpha} - \frac{D_L}{n\,\sigma} + \frac{D_L - D_S}{3\,n\,\sigma}, \\ r_S &= \frac{p_1\, y_1 - \alpha\, r_k}{1-\alpha} - \frac{D_S}{n\,\sigma} - \frac{D_L - D_S}{3\,n\,\sigma}. \end{aligned} \tag{8}$$

[16]Comparative statics would be unchanged if we always picked the inferior equilibrium.

Small banks offer higher deposit rates than the large bank. Because they have a smaller clientele, raising deposit rates is less costly for them, hence they act more aggressively ($r_S > r_L$) in order to attract a larger market share. When competition increases (σ rises), both types of banks increase their deposit rates. As equilibrium deposit volumes, we obtain

$$\begin{aligned} d_L &= D_L - \frac{D_L - D_S}{3}, \\ d_S &= D_S + \frac{D_L - D_S}{3\,n}, \end{aligned}$$

hence volumes do not depend on competition σ. Expected profits are

$$\Pi_L = \frac{1}{9\,n\,\sigma}\,\big(2\,D_L + D_S\big)^2 \quad \text{and} \quad \Pi_S = \frac{1}{9\,n\,\sigma}\,\big(2\,D_S + D_L\big)^2.$$

Regime 2: Small banks above the kink At some point, the small banks, offering the higher rate, are going to reach the critical rate r^{crit}. They know that if they raised deposit rates further, depositors would anticipate that the bank will choose the inefficient project, and demand an additional default premium. Therefore, small banks optimally leave their rates unchanged, foregoing some market share. This weakens competition for the large bank, which now sets a lower rate than it would in the absence of the moral hazard problem. However, as long as its deposit rate is below r^{crit}, the large bank increases its deposit rate as σ rises, albeit not as strongly as before. Formally, deposit rates are given by

$$\begin{aligned} r_L &= \frac{1}{2}\Big(\frac{p_1\,y_1 - \alpha\,r_k}{1-\alpha} + r^{\text{crit}} - \frac{D_L}{n\,\sigma}\Big), \\ r_S &= r^{\text{crit}}, \end{aligned}$$

and deposit volumes by

$$\begin{aligned} d_L &= \frac{D_L}{2} + \frac{n\,\sigma}{2}\left(\frac{p_1\,y_1 - \alpha\,r_k}{1-\alpha} - r^{\text{crit}}\right), \\ d_S &= \frac{D_L + 2\,D_S}{2\,n} - \frac{\sigma}{2}\left(\frac{p_1\,y_1 - \alpha\,r_k}{1-\alpha} - r^{\text{crit}}\right). \end{aligned}$$

Now the large bank grows with increasing competition, while the small banks shrink.

Regime 3: All banks above the kink For higher competition, the large bank also reaches the critical rate r^{crit}.[17] Then both types of banks offer the same rate

$$r_L = r_S = r^{\text{crit}}.$$

[17]If small and large banks are sufficiently asymmetric ($D_L \gg D_S$), or if the moral hazard problem is small ($p_1\,y_1 \approx p_2\,y_2$), it may happen that the small banks reach r^{jump} before the large bank reaches r^{crit}. This would give rise to an additional regime. We do not explicitly treat this regime in the paper because it does not provide any additional insights, but just makes the discussion more cumbersome.

The nominal rate is also identical because all banks take the safe project. Hence no bank can attract any customers from another bank, and deposit volumes are equal to the respective clienteles,

$$d_L = D_L \qquad \text{and} \qquad d_S = D_S.$$

Regime 4: Small banks above the jump At some point, it becomes profitable for the banks to raise their deposit rates. The higher the competition, the easier it is to steal each others' customers; poaching becomes more attractive. Due to their smaller clienteles, the small banks will be the first to raise their deposit rates above the critical rate. However, they now have to accept higher (nominal) refinancing costs because depositors anticipate that small banks will take the risky project. In order to attract part of the large bank's customers, small banks will increase their deposit rates by so much that even the expected deposit rates will jump up. The large bank will stick to the lower deposit rate, accepting a decrease in its market share. Equilibrium rates are

$$\begin{aligned} r_L &= r^{\text{crit}}, \\ r_S &= \frac{1}{2}\Big(\frac{p_2\, y_2 - \alpha\, r_k}{1-\alpha} + r^{\text{crit}} - \frac{D_S}{n\,\sigma}\Big), \end{aligned} \tag{9}$$

yielding the deposit volumes

$$\begin{aligned} d_L &= \frac{2\,D_L + D_S}{2} - \frac{n\,\sigma}{2}\left(\frac{p_1\, y_1 - \alpha\, r_k}{1-\alpha} - r^{\text{crit}}\right), \\ d_S &= \frac{D_S}{2\,n} + \frac{\sigma}{2}\left(\frac{p_1\, y_1 - \alpha\, r_k}{1-\alpha} - r^{\text{crit}}\right). \end{aligned}$$

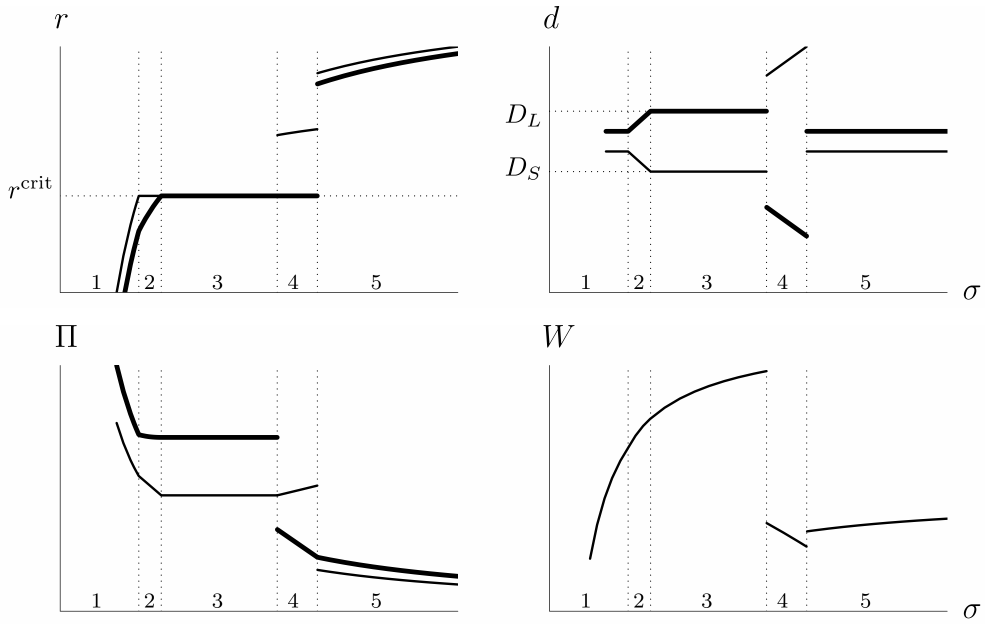
The increase in small banks' deposit rates may be so large that the large bank also finds it beneficial to raise its rate. Then regime 3 may directly be followed by regime 5 (see Figure 4 for an illustration).

Regime 5: All banks above the jump Finally, even the large bank finds it profitable to raise deposit rates sharply and signal that it will take the risky project. From this point on, all banks take the risky project. The small banks react by raising deposit rates as well, but not as sharply as the large bank. Therefore, the small banks will lose some of the market share they had gained before. However, the small banks' rate will continue to exceed the rate at the large bank.

Similar to (8), we obtain

$$\begin{aligned} r_L &= \frac{p_2\, y_2 - \alpha\, r_k}{1-\alpha} - \frac{D_L}{n\,\sigma} + \frac{D_L - D_S}{3\,n\,\sigma}, \\ r_S &= \frac{p_2\, y_2 - \alpha\, r_k}{1-\alpha} - \frac{D_S}{n\,\sigma} - \frac{D_L - D_S}{3\,n\,\sigma}. \end{aligned}$$

Figure 3: Equilibrium Deposit Rates, Volumes, Profits, and Welfare



Thick lines denote the large bank, thin lines the small banks. For deposits and profits, *aggregate* amounts for the group of small banks are plotted. Numbers on the abscissa indicate regimes.

The expressions for deposit volumes and profits are the same as in regime 1; yet, profits are much lower due to higher competition and, hence, higher deposit rates.

We now discuss how banks' profits are affected by the different regimes (see the bottom left panel of Figure 3). In general, increasing competition decreases profits. The reason is that banks have to offer higher interest rates to prevent their depositors from switching to another bank. Thereby they exert a negative externality on their competitors. In our model, this externality is very strong because of the inelastic aggregate supply of deposits; the qualitative result would still hold if the supply of deposits was elastic (but not perfectly elastic). However, in some regimes, the moral hazard problem prevents some banks from raising rates, which implies a drop in their market shares and profits if the competitor bank continues to raise rates. For example, in regime 4, the large bank does not offer higher rates, whereas small banks raise rates in response to higher competition. Even though this reduces small banks' margins, it may boost their profits due to the gains in market shares. Hence, in regime 4, small banks may actually *profit* from an increase in competition (or, more precisely, substitutability) because it makes it easier to attract the large bank's depositors (see Figure 3 for an example of this phenomenon). The large bank's deposit rate is a suboptimal response to the rate of the competitor bank, and the bank's profits decrease. If both large and small banks are unwilling to raise rates (regime 3), an increase in σ leaves volumes, rates and profits unaffected.

Finally, we analyze the effects of competition on welfare (see the bottom right panel of Figure 3). In our model, welfare consists of three components: the proceeds from the project, the opportunity costs of equity finance, and the depositors' transportation costs. The opportunity costs of depositors do not have to be taken into account because they are constant, given that the aggregate deposit volume is constant. Interest and dividend payments are welfare-neutral. Hence, the welfare function is

$$W = \sum_j \left[(p_j\, y_j)\, d_j - (r_k - p_j\, y_j)\, k_j \right] - \text{transportation costs}$$
$$= \sum_j d_j\, \frac{p_j\, y_j - \alpha\, r_k}{1-\alpha} - \text{transportation costs.}$$

The aggregate opportunity costs from equity finance (i. e., $n\,\lambda\, r_k\, \alpha/(1-\alpha)$) do not depend on σ. Hence, competition affects welfare through two factors: the banks' project choices and transportation costs. In regimes 1 to 3, all banks choose the safe project, hence the first welfare component is relatively high and constant across these regimes. In regime 4, small banks take the risky project and expand, leading to an increasing welfare loss. Finally in regime 5, both types of banks take the risky project. This has a further negative impact on welfare. This negative dependence of welfare on competition is similar to the prediction of the literature on the trade-off between banking stability and competition. Regarding the second welfare component, there are two effects: First, welfare decreases if deposit rates become asymmetric because this increases transportation costs. Second, transportation costs affect welfare directly; a higher σ corresponds to lower transportation costs, and hence higher welfare. The first effect implies that welfare is relatively high in regime 3, where all banks serve their own clienteles (which minimizes transportation costs). The second effect implies that welfare tends to increase in σ. Taken together, these considerations imply that, if transportation costs are not too large, welfare as a function of α reaches a global optimum at the border between regimes 3 and 4. The exact form of the welfare function depends on the relative significance of the difference in the projects' expected returns and the size of transportation costs. Figure 3 presents an example of the complicated form that this function may have. Finally, due to our assumption of a completely inelastic deposit supply, there is no deadweight loss from imperfect competition. With an elastic deposit supply, higher competition would decrease the deadweight loss and hence increase welfare.

4.4 The Impact of Capital Regulation

So far, we have been holding capital regulation constant. Now we ask how the banks respond to a tightening of capital requirements. We first consider what happens *within* the regimes described in the preceding section. Then we discuss regime switches triggered by tightened regulation. In general, an increase in capital requirements has two effects: First, it reduces the profitability of banking due to higher capital costs; this tends to lower deposit rates. Second, it raises the critical interest rates and thereby relaxes the constraints on deposit rates in regimes 2, 3, and 4; this tends to increase deposit rates. Table 1 summarizes the qualitative results for all regimes. The algebra is straightforward, and is therefore omitted.

In *regimes 1 and 5*, only the first effect is present. Higher capital requirements reduce the profitability of banking. This makes banks less aggressive in the deposit

Table 1: Comparative Statics Within Regimes for Changes in Capital Requirements

Regime	1	2	3	4	5
$\partial r_L/\partial\alpha$	$-$	$+/-$	$+$	$+$	$-$
$\partial d_L/\partial\alpha$	0	$-$	0	$+$	0
$\partial\Pi_L/\partial\alpha$	0	$-$	$-$	$+/-$	0
$\partial r_S/\partial\alpha$	$-$	$+$	$+$	$+/-$	$-$
$\partial d_S/\partial\alpha$	0	$+$	0	$-$	0
$\partial\Pi_S/\partial\alpha$	0	$+/-$	$-$	$-$	0

The table entries give the signs of the partial derivatives. $+/-$ means that the sign is ambiguous.

market and reduces deposit rates for all banks. Since small and large banks lower their rates by the same amount, deposit volumes remain unchanged. The lower refinancing costs due to lower deposit rates completely offset the deterioration in profitability due to higher capital costs. The increase in the capital costs is shifted entirely to the depositors, and banks' profits remain unchanged.[18]

In *regime 2*, only small banks are constrained by the critical rate r^{crit}. As capital requirements are tightened, the critical rate rises, which allows the small banks to raise their deposit rates to the new r^{crit} and expand. The small banks' profits may even increase, in spite of higher capital costs. Given the inelastic aggregate supply of deposits, the large bank must shrink. The effect on the large bank's deposit rate is ambiguous. On the one hand, the rate increase by the small banks induces the large bank to raise its rate as well. On the other hand, the investment becomes less profitable due to higher equity costs; this reduces competition for deposits and induces the large bank to decrease its rate. In any case, the large bank's profits fall.

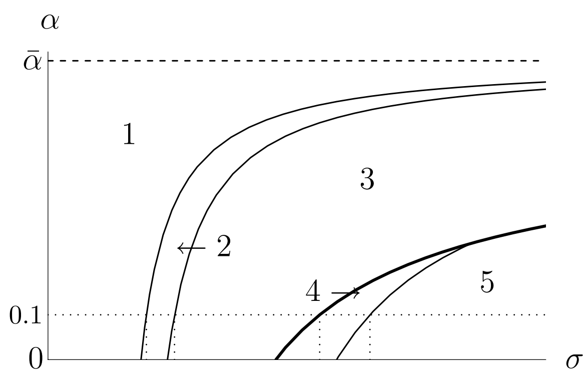
In *regime 3*, both types of banks are above the kink, but below the jump. Tightened regulation relaxes the constraints on deposit rates for large and small banks. However, because both types of banks raise their deposit rates, volumes remain unchanged, and profits of all banks decrease. The result on volumes is driven by our assumption that deposits are constant at the aggregate level. If we relaxed this assumption, volumes would increase in the presence of tightened regulation.[19] Then a tightening of regulation might even have an *expansionary* effect on the banking sector because it attenuates the moral hazard problem.

Finally, in *regime 4*, small banks prefer to take the risky project. The effects of tightened capital regulation are the same as in regime 2, with reversed roles. Now only the large bank is constrained by the critical rate r^{crit}. When this constraint is relaxed, the large bank can raise its rate and expand at the expense of small banks. Small banks may raise or lower their rates, and will shrink unambiguously. The large bank may increase its profits, whereas the small banks will always lose.

[18]This result is typical for models of spatial competition, like those by Hotelling (1929) or Salop (1979). It is driven by the inelastic deposit supply.

[19]However, profits may decrease even in the presence of an elastic aggregate supply of deposits.

Figure 4: Regimes for Varying α and σ, standardized approach



The numbers mark the areas of the different regimes as described in the text. The dotted horizontal line refers to $\alpha = 0.1$, the example used in the previous figures. The dashed line marks $\bar{\alpha} = p_1\, p_2\, (y_2 - y_1)/(p_1 - p_2)/r_k$ (here $\bar{\alpha} = 2/3$), above which only regime 1 exists.

The preceding discussion suggests that a tightening of capital requirements may lead to an expansion of one type of bank in certain cases. Of particular interest is regime 2, where small banks may expand in the face of tightened regulation. If one assumes that small banks are specialized in financing small and medium enterprises (SMEs), this result implies that the financing of SMEs is not necessarily choked by capital adequacy. In fact, the opposite may be true.

In our model, a tightening of capital regulation in most cases reduces welfare in the absence of regime switches. The reason is that higher capital adequacy increases the inefficiencies arising from equity finance, while leaving the aggregate level of deposits unchanged.[20] If the aggregate supply of deposits were very elastic, welfare increases would be conceivable in all regimes, even without regime switches. More importantly, welfare increases can be obtained if the tightening of regulation induces a switch to a regime with lower risk-taking. Figure 4 illustrates such regime switches for a numerical example: Starting from a regime where one or both types of banks opt for the risky project (regimes 4 or 5), an increase in α eventually leads to a switch into a regime where both types of banks opt for the safe project (holding competition σ constant). The following proposition formalizes this result.[21]

Proposition 1 (Standardized Approach) *Higher capital requirements increase the critical levels of competition σ_S^{crit} and σ_L^{crit}, above which small and large banks choose the risky project, i. e., $\partial\sigma_S^{\text{crit}}/\partial\alpha > 0$ and $\partial\sigma_L^{\text{crit}}/\partial\alpha > 0$.*

Graphically, the proposition implies that the border between the area where all banks choose the safe project (regimes 1, 2, and 3) and the remaining area (regimes 4

[20] In some regimes, the capital regulation also has an effect on transportation costs because it increases (regime 2) or decreases (regime 4) the deposit rate differentials. In the latter case, the overall effect of the regulation on welfare may even be positive.

[21] The proofs of propositions and remarks are found in the Appendix.

and 5), and the border between regimes 4 and 5 are strictly increasing (see Figure 4). In fact, this is true for all borders. Economically, the proposition implies that switching to the risky project becomes less attractive when capital requirements are higher. When competition increases, banks have an incentive to increase their rates to capture some market share from their competitor. However, the increase in deposit rates is bounded above by the return that banks earn from their projects. If, in regime 3, r^{crit} increases due to tighter regulation, the implied increase in deposit rates limits the scope for further rate increases. Hence, offering higher rates (and switching to the risky project) becomes less attractive for small banks. An analogous argument applies to the large bank at the border between regimes 4 and 5.

Proposition 1 implies that higher capital requirements reduce the range of σ, for which at least one type of bank opts for the risky project (regimes 4 and 5). According to the following remark, this statement can be generalized to any other parameter of our model: For *any* parameter of our model, the range of regimes 4 and 5 shrinks in reaction to an increase in α.

Remark 1 *Higher capital requirements weakly reduce the set of parameters for which at least one type of bank chooses the risky project.*

We can conclude that, in our model, a suitably designed capital regulation can increase welfare because it may induce banks to switch from the risky to the safe project. An optimal regulation would try to deter banks from choosing inefficient risks, while minimizing the costs of equity finance. If the costs of equity are not prohibitively high, this would be achieved at the border between regimes 3 and 4.

5 The IRB Approach

So far, we have discussed an economy in which all banks use the standardized approach. Now we turn to the IRB approach. We first assume that all banks must adopt the IRB approach (Section 5.1). Then we analyze the banks' right to choose between the two approaches, envisioned by the new Basel Accord (Section 5.2).

5.1 Compulsory IRB Approach

In this section, we assume that the IRB approach according to (2) and (3) is compulsory for all banks. What are the implications of switching from the standardized to the IRB approach? Clearly, the answer depends on whether the regulation has become stricter or looser. We assumed above that banks need less capital if they choose the safe project, compared to the standardized approach, and more capital if they choose the risky project, i. e., $\beta_1 < \alpha < \beta_2$. Our qualitative results are independent of how much β_1 lies below α, and β_2 above it.

Using the same procedure as in Section 4.1, we derive the critical rate $\dot{r}^{\text{crit}}$. For distinction, we put a dot on variables that refer to the compulsory IRB approach. Let Π^1 again denote the expected profits of a bank that chooses the safe project as anticipated by the depositors, and Π^2 the profits of a bank that deviates by taking the risky project. We then get

$$\begin{aligned} \Pi^1 &= (1-\delta_1)\, p_1\, (y_1\,(d+k_1) - r\,d/p_1) - C, \quad \text{with} \\ k_1 &= \delta_1\, p_1\, (y_1\,(d+k_1) - r\,d/p_1)/r_k \end{aligned}$$

if the bank takes the safe project, and

$$\begin{aligned} \Pi^2 &= (1-\delta_2)\, p_2\, (y_2\,(d+k_2) - r\,d/p_1) - C, \quad \text{with} \\ k_2 &= \delta_2\, p_2\, (y_2\,(d+k_2) - r\,d/p_1)/r_k \end{aligned}$$

if the bank deviates, yielding

$$\begin{aligned} \Pi^1 &= d\left(\frac{p_1\,y_1 - \beta_1\,r_k}{1-\beta_1} - r\right) - C, \quad \text{and} \\ \Pi^2 &= d\left(\frac{p_2\,y_2 - \beta_2\,r_k}{1-\beta_2} - \frac{p_2}{p_1}\,r\right) - C. \end{aligned}$$

The critical deposit rate is then

$$\dot{r}^{\text{crit}} = \frac{p_1}{p_1 - p_2}\left(\frac{p_1\,y_1 - r_k}{1-\beta_1} - \frac{p_2\,y_2 - r_k}{1-\beta_2}\right).$$

One can check that, for $\beta_1 = \beta_2 = \alpha$, the critical rate is the same as in the standardized approach (see (5)). Comparative statics are $\partial\dot{r}^{\text{crit}}/\partial\beta_1 < 0$ and $\partial\dot{r}^{\text{crit}}/\partial\beta_2 > 0$. Raising β_1, while holding β_2 constant, lowers the relative costs of risk-shifting; raising β_2, while holding β_1 constant, increases them. Given our assumptions on β_1 and β_2, $\dot{r}^{\text{crit}}$ is strictly larger than r^{crit}.[22] In contrast to the standardized approach, the critical rate also depends on the cost of equity r_k, with $\partial\dot{r}^{\text{crit}}/\partial r_k > 0$. Higher capital costs make risk-shifting less attractive because they raise the costs of the risky project relative to those of the safe project. This implies that, under the IRB approach, an increase in the costs of capital has a similar effect as a tightening of regulation. Hence, higher costs of capital allow the regulator to loosen regulation without inducing risk-shifting. This was not true under the standardized approach. Fixed costs C are irrelevant for the marginal analysis and for risk-shifting.

The introduction of the IRB approach has two effects: First, it decreases the capital requirements for the safe project and increases them for the risky project. The effects are similar to those deriving from a loosened or tightened capital regulation in the standardized approach. Second, it raises the critical rate. The qualitative properties

[22] The fact that $\dot{r}^{\text{crit}}$ lies above (and possibly well above) r^{crit} is crucial for the model when we introduce the right to choose between different regulatory approaches. If, for example, banks' deposit rates are constrained by r^{crit} (as in regime 3), they have an incentive to implement the IRB approach in order to overcome this constraint and raise rates, but not farther than $\dot{r}^{\text{crit}}$.

of banks' reaction functions are the same as under the standardized approach (see Figure 2). As a result, we again have five regimes, depending on whether banks are below or above the kinks and the jumps of their reaction functions.

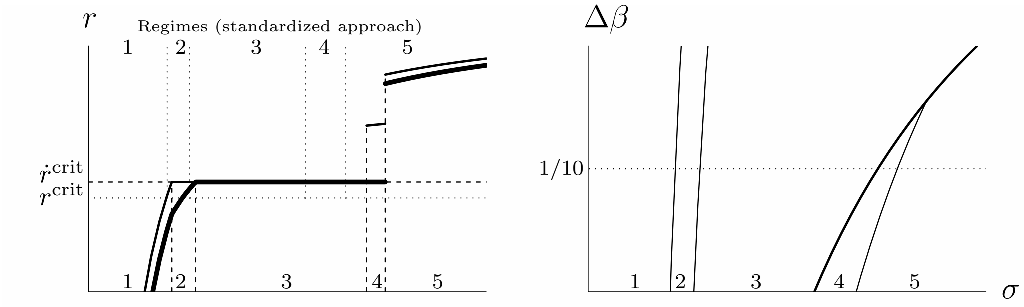
We start again by describing the behavior of banks within regimes, before discussing regime switches. If both types of banks are below the kink (regime 1), they will offer higher deposit rates. Lower capital requirements make the investment more profitable, hence the competition for deposits becomes more severe. The opposite is true when all banks are above the jump (regime 5). Here, because both types of bank take the risky project, capital adequacy is tightened, and deposit rates drop.

In regime 2, all banks raise their rates. Small banks raise their rates because the increase in the critical rate (from r^{crit} to $\dot{r}^{\text{crit}}$) relaxes the constraints on their deposit rate policies. The large bank raises its rate because the small banks raise their rates, and because investing becomes more profitable. However, the rate increase at the large bank is less pronounced than at the small banks. This allows the small banks to "recapture" some market share from the large bank. Remarkably, this may even lead to increased profits at the small banks. As a result, small banks may benefit from a transition from the standardized to the compulsory IRB approach. In contrast, the large bank shrinks, and its profits are always decreased compared to the standardized approach. These results are interesting because they contradict the frequently made assertion that small borrowers are bound to suffer from the IRB approach. We see that, under the compulsory IRB approach, small banks may actually gain relative to the large bank. If small banks primarily serve small borrowers, our results suggest that the IRB approach may actually have an expansionary effect on SME borrowing.

In regime 3, all banks raise rates after the transition to the IRB approach because of the increase in the critical rate. This results in lower profits for both bank types. Finally, in regime 4, the large bank raises its rate because of the increase in the critical rate. The reaction of small banks is ambiguous. On the one hand, they want to raise rates in reaction to the large bank's rate increase. On the other hand, they want to cut rates because they are subject to a stricter capital requirement, rendering investment less attractive.

As before, we are interested most in whether the transition from the standardized to the IRB approach can deter banks from choosing the risky project. Figure 5 presents a numerical example. The left panel shows equilibrium deposit rates in the IRB approach for different levels of competition, as well as the levels of competition at which regime switches occur in the standardized approach. Apparently, all regime switches move towards higher competition. In the right panel, the critical σ's of the regime switches are plotted for varying $\Delta\beta = \beta_2 - \beta_1$, measuring the degree of differentiation in the IRB approach. The thick curve denotes the critical σ, above which at least one bank type chooses the risky project. The curve increases monotonically. Similarly, the border between regimes 4 and 5 increases monotonically. Hence, the more the IRB approach differentiates among risks, the more competitive markets must be to induce banks to choose the risky project. The following proposition states that these results are true for any parameter constellation. As before, the other borders increase as well. The proofs are analogous.

Figure 5: Equilibrium Deposit Rates and Regime Switches, IRB approach



In the left panel, the thick line denotes the large bank, the thin line the small banks. Dotted lines correspond to the *standardized* approach, dashed lines to the *IRB* approach. In the figure, $\beta_1 = 1/20$ and $\beta_2 = 3/20$. The right panel plots the critical σ's of the different regimes for varying $\Delta\beta = \beta_2 - \beta_1$. The dotted horizontal line refers to the parameters of the left panel, $\Delta\beta = 1/10$.

Proposition 2 (Compulsory IRB approach) *A transition from the standardized to a compulsory IRB approach increases the critical levels of competition σ_S^{crit} and σ_L^{crit}, above which small and large banks choose the risky project, i. e., $\partial\sigma_S^{\text{crit}}/\partial\Delta\beta > 0$ and $\partial\sigma_L^{\text{crit}}/\partial\Delta\beta > 0$.*

Because switching to the risky project is more costly than under the standardized approach, both types will start to raise rates (and signal that they will take the risky project) at a more competitive stage. Similar to Remark 1, the transition from the standardized to a compulsory IRB approach weakly reduces the set of (any) parameters for which at least one type of bank takes the risky project.

Let us discuss the effects of the transition on welfare. Within the regimes, the IRB approach reduces the inefficiencies from capital finance relative to the standardized approach if banks choose the safe project (regimes 1 to 3). The opposite is true when both banks take the risky project (regime 5). In regime 4, the effect is ambiguous because capital requirements increase for one bank, but decrease for the other.[23] More importantly, welfare may be increased relative to the standardized approach because the IRB approach is better than the standardized approach at deterring banks from choosing the risky project. However, banks have to incur fixed costs C under the IRB approach, which reduces welfare. In fact, these fixed costs may be so high that some banks are driven out of business. In our model, this may increase or decrease welfare, depending on the size of fixed costs and transportation costs.

An optimal compulsory IRB regulation would try to induce all banks to opt for the safe project and save on capital costs. Hence, within our model with two projects, the regulator optimally chooses a corner solution: He sets $\beta_1 = 0$ and $\beta_2 = 1$, so that risk-taking becomes prohibitively expensive, and capital costs are reduced to zero. Therefore, if fixed costs are not too high, the IRB approach is superior to the

[23] Again there are additional welfare effects due to changing interest differentials, which are clearly negative in regime 2 and ambiguous in regime 4.

standardized approach in terms of welfare because it economizes on capital. Hence, we can conclude that the compulsory transition from the standardized to the IRB approach achieves its goal as long as the fixed costs C are not too high.

5.2 The Right to Choose

In the preceding section, we assumed that all banks have to adopt the IRB approach. However, the new Basel Accord does not make such a prescription. Instead it allows banks to *choose* between the standardized and the IRB approaches. This right to choose fundamentally changes our assessment of the regulation.

Banks will opt for the IRB approach if this increases their profits, given the regulatory approaches and deposit rates of their competitor banks. If fixed costs C are so high that neither small nor large banks choose the IRB approach, we end up in the situation discussed in Section 4. If fixed costs C are so low that all bank types opt for the IRB approach, we end up in the situation discussed in Section 5.1. The interesting case is the intermediate situation where switching to the IRB approach is profitable only for the large bank.[24]

Since small banks retain the standardized approach, their capital requirement is α. For the large bank, the requirement is reduced to β_1 because the large bank never chooses the risky project. If it did, regulation would become stricter because of the IRB approach; hence the investment C could not be profitable. As a result, competition must be relatively low. Furthermore, the IRB approach will allow the large bank to offer higher deposit rates. If the large bank has not yet reached the critical deposit rate, it will raise rates because the investment becomes more profitable. If it *has* reached the critical rate, it will raise rates because the critical rate rises. In both cases, competition for deposits increases.

Let us consider first what happens within the regimes. We put double dots on parameters that refer to the optional IRB approach. Regime 5 does not need to be considered here because it would imply that the large bank takes the risky project, rendering the choice of the IRB approach unprofitable.

In regime 1, equilibrium deposit rates are

$$\ddot{r}_L = r_L + \frac{2\,(\alpha-\beta_1)\,(r_k - p_1\,y_1)}{3\,(1-\alpha)\,(1-\beta_1)},$$

[24]The set of possible parameter settings is not empty: If C were negligible, all banks would (individually) benefit from switching to the IRB approach, unless they would take the risky project even after a switch to IRB. Now because of the assumed structure of competition, if we set $\sigma \sim 1/n$, the large bank's profits are independent of n, whereas the small banks' profits are inversely proportional to n. Therefore, for each C (and other parameters of the model), we must only choose n large enough to render the IRB approach unprofitable for small banks. Only for very high competition (large σ), *no* bank takes the IRB approach even for vanishing C. All banks will take the risky project anyway, so they would hurt themselves by opting for the IRB approach.

$$\ddot{r}_S = r_S + \frac{(\alpha - \beta_1)\,(r_k - p_1\,y_1)}{3\,(1-\alpha)\,(1-\beta_1)},$$

yielding deposit volumes of

$$\ddot{d}_L = d_L + \frac{n\,\sigma}{3}\,\frac{(\alpha - \beta_1)\,(r_k - p_1\,y_1)}{3\,(1-\alpha)\,(1-\beta_1)},$$
$$\ddot{d}_S = d_S - \frac{\sigma}{3}\,\frac{(\alpha - \beta_1)\,(r_k - p_1\,y_1)}{3\,(1-\alpha)\,(1-\beta_1)}.$$

Hence in regime 1, deposit rates of all banks rise. The large bank raises its rate because investment becomes more profitable, and the small banks raise their rates in reaction to the large bank. However, the rate increase of the large bank is much larger. As a result, the large bank increases its market share at the expense of the small banks. The large bank's profits increase, those of the small banks decrease.

In regime 2, small banks have reached the critical rate. Because r^{crit} is independent of competition, we have $r_S = r^{\text{crit}}$, as defined in (5). The switch to the IRB approach induces the large bank to increase its deposit rate. Because the rates of small banks are constrained, small banks shrink, and the large bank grows. Profits of small banks decrease, whereas those of the large bank increase.

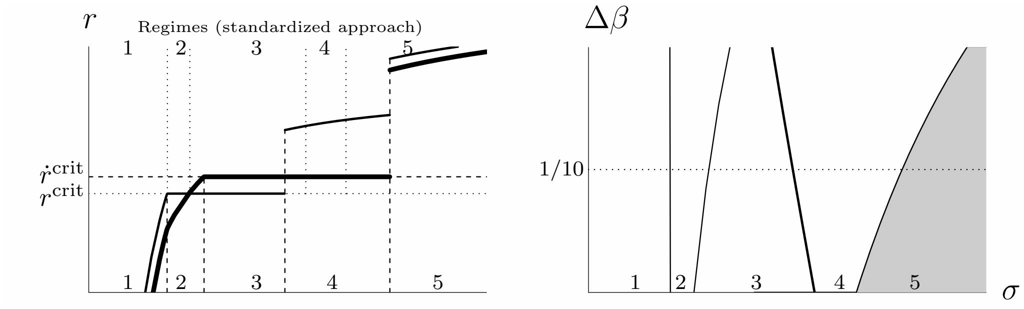
In regime 3, deposit rates were $r_S = r_L = r^{\text{crit}}$, as defined in (5), when all banks were using the standardized approach. Now r_L rises to $\dot{r}^{\text{crit}}$. As a result, the large bank increases its market share, whereas small banks loose some market share. Again the profits of the small banks decrease, whereas those of the large bank increase.

In regime 4, the large bank's deposit rate rises to $\dot{r}^{\text{crit}}$. The rates of the small banks are like those in (9), replacing r^{crit} by $\dot{r}^{\text{crit}}$. Hence, the deposit rates of all banks rise. However, the large bank's rate rises more, increasing the large bank's market share. As before, the profits of the large bank increase, those of small banks drop.

The discussion has shown that, within each regime, the small banks undergo a reduction in volumes and profits if the large bank switches from the standardized to the IRB approach. In contrast, the large bank benefits from the right to choose between regulatory approaches. We now consider the effects of regime changes when the large bank switches to the IRB approach. This is particularly problematic if small banks switch to the risky project, i. e., the regime switches from 3 to 4. Such a regime switch would increase aggregate risk in the economy, and market rates would jump up.[25] The following proposition shows that the transition to an optional IRB approach may indeed lead to a switch from a regime without risk-taking (regimes 1, 2, or 3) to one with risk-taking (regime 4).

[25]It is not possible that the regime switches to 5, i. e., that the large bank also takes the risky project in reaction to the jump in deposit rates. The large bank would anticipate this, and as a consequence, not opt for the IRB approach in the first place.

Figure 6: Equilibrium Deposit Rates and Regime Switches, Right to Choose



Curves are as in Figure 5. The important difference is that the thick line in the right panel *falls* monotonically if banks are allowed to choose between the approaches. The area of regime 5 is plotted in gray because it cannot occur here. Again, the dotted horizontal line in the right panel refers to the parameter constellation of the left panel, $\Delta\beta = 1/10$.

Proposition 3 (Optional IRB approach) *Given that only the large bank switches to the IRB approach, a transition from the standardized to an optional IRB approach decreases the critical level of competition* σ_S^{crit}*, above which small banks choose the risky project, i. e.,* $\partial\sigma_S^{\text{crit}}/\partial\Delta\beta < 0$*.*

Hence, rather than deterring banks from risk-taking, the optional IRB approach may lead the small banks to engage in *more* risk-taking. The reason is that, under the optional IRB approach, only the large bank benefits from lower capital requirements, and hence marginal costs. This induces the large bank to expand and increase deposit rates, putting the small banks under competitive pressure. In reaction, the small banks may raise deposit rates to regain part of their customer base, and take the risky project. This translates into an increase in aggregate risk in the economy, given that the large bank always chooses the safe project. If we assume that the regulator set α optimally for the standardized approach, the right to choose will *always* induce small banks to increase risk-taking: An optimal α implies that the economy is at the border between regimes 3 and 4; the right to choose then moves the economy into regime 4.

The proposition is illustrated in Figure 6. The left panel displays equilibrium deposit rates if there is a right to choose between the two approaches. We see that the border between regimes 3 and 4 actually moves towards *lower* competition, compared to the standardized approach. As a result, risk-taking is *increased* by the regulation. At the former border between regimes 3 and 4, the small banks now strictly prefer to increase rates. The same result can be found in the right panel. In contrast to Figure 5, the curve separating the regimes with and without risk-taking *falls* monotonically. Hence, if banks are allowed to choose between the two approaches and if only the large bank switches to the IRB approach, a more pronounced IRB approach enlarges the set of parameters σ for which (small) banks take excessive risks. Again, an analogous version of Remark 1 applies.

Even if the regime switches to regime 4, the small banks are bound to suffer. For the purpose of illustration, assume that the banks are at the border between regimes 3 and 4 before the introduction of the optional IRB approach. Then an infinitesimal increase in $\Delta\beta$ has two effects: First, it induces the small banks to increase deposit rates discretely, which leaves their profits unchanged at the margin. Second, it increases the large bank's deposit rate, which unambiguously hurts the small banks. Therefore, the small banks' profits will fall even when there are regime switches.

Interestingly, even the large bank may suffer in the event of a regime switch. This result is surprising at first sight, given that the large bank should only choose the IRB approach if it is beneficial. However, in choosing the approach, the large bank takes the small banks' interest rates as given. Hence, the possible transition from regime 3 to regime 4 does not enter the large bank's considerations. Starting from the border between regimes 3 and 4, an infinitesimal increase in $\Delta\beta$ has two effects: First, the large bank raises its rate by an infinitesimal amount due to the increase in the critical rate; second, the small banks raise their rates discretely because they want to increase their market shares. An increase in the small banks' market shares implies a decrease in the large bank's profits. Hence, the large bank's profits may actually fall after the transition from the standardized to the optional IRB approach.

In all other cases, the large bank will always benefit from a transition from the standardized to the optional IRB approach. This yields a political economy rationale, explaining why certain interest groups may lobby the regulatory authorities for a highly sophisticated IRB approach. The more sophisticated the approach, the higher the fixed costs, and the less smaller banks will be willing to adopt the new approach. The potential benefits from the IRB approach for the large bank are largest when only a small number of banks switch to the new approach. The small banks, whose interests are less well organized, suffer from the introduction of the IRB approach *because* its use is only optional. However, given the degree of sophistication of the IRB approach, an adoption by all banks is not feasible.

In summary, we have shown that introducing an optional IRB approach may induce the small banks to take higher risks, which brings about an increase in aggregate risk, compared to the standardized approach. Therefore, the regulation does not achieve its goal of deterring banks from risk-taking. The right to choose destroys the advantages of the IRB approach.

6 Conclusion

Our paper has presented a novel channel through which the New Basel Capital Accord may harm small banks and lead to an increase in the aggregate risk in the economy. We started from the observation that the new accord implicitly treats small and large banks asymmetrically: Due to the high fixed costs from implementation, it is very likely that only large banks will opt for the IRB approach. Then small banks will not benefit from the lower capital requirements for safe loans. This distorts competition, benefiting the larger banks, whose capital requirements, and hence marginal costs, are reduced when adopting the IRB approach. Large banks increase deposit rates to attract more deposits and exploit the higher profitability of investments. Fiercer competition for deposits induces the small banks to raise their deposit rates as well, in order to recapture some of their market shares. At this higher rate, small banks may prefer a risky investment strategy over a safe one. Starting from a situation where all banks choose a safe investment strategy, this implies an increase in aggregate risk. Hence, the new accord may actually *destabilize* the banking system, contrary to the regulators' intention.

Our results do not follow from the introduction of the IRB approach as such, but rather from the implicit asymmetric treatment of banks due to the right to choose between the standardized and the IRB approaches. If the IRB approach is applied uniformly across banks, banking stability is improved as intended. Small banks may even profit from the introduction of the IRB approach.

Our model relies on three important ingredients to obtain these results: the existence of a moral hazard problem regarding the banks' risk choices, imperfect competition among banks, and equity that is more expensive than other sources of refinancing. In contrast, the details of the market structure are not crucial for our results. For example, one may consider a banking system with *several* large banks competing with each other. This would weaken the competitive position of the large bank, but would leave the general structure of the model unchanged. As long as the large banks are larger than the small banks, there will be a range of fixed costs C, for which only large banks implement the IRB approach. Marginal costs of lending decrease for large banks, and small banks suffer because of fiercer competition, which may lead them to switch to the risky project. Similarly, one could allow for competition among the small banks. This would complicate the analysis because all banks would have to be analyzed simultaneously. But the decrease in marginal costs at the large bank would still increase competition for deposits at the small banks, and would push them to assume higher risks. Furthermore, we have modelled competition among banks as price competition à la Hotelling (1929). Different types of competition, such as competition in capacities à la Cournot, would not alter our results, as long as the banks suffer from the lower marginal costs of their competitors.

Another simplifying assumption is that aggregate deposits are perfectly inelastic. Generally, the aggregate supply of deposits depends on deposit rates. Again, our main results remain valid under this alternative assumption. In particular, the qualitative results regarding the risk-taking of banks are not affected. However, the effects of competition and regulation on profits and welfare would be slightly different because increases in deposit rates could lead to an aggregate increase in aggregate deposits. This would weaken the negative externality from interest rate increases on the competitor banks. Also, the volume expansion would tend to increase welfare, especially if the aggregate deposit supply was very elastic.

Let us now discuss the assumptions that may be more critical. We assumed that banks' risk choices are dichotomous, i. e., banks can choose between two projects. Given that the large bank's risk-taking cannot change for the better, an increase in risk by the small banks always translates into an increase in aggregate risk. The same can happen with continuous risk choices. But there, the introduction of an optional IRB approach may also change all banks' risk-taking continuously, leading to higher risk at the small banks and lower risk at the large bank. Hence, the effect on aggregate risk is ambiguous. Even in such a model, there will be parameter constellations for which aggregate risk-taking increases. In any case, it is alarming that the new capital regulation may lead to the opposite of what is intended.

Another assumption concerns the modelling of bank competition. We assumed that large and small banks compete only in the deposit market, but not in the loan market. We have argued above that, due to the fact that banks specialize in different types of loans, this is a good approximation of real-world competition between large and small banks. In fact, our main results still hold in the presence of loan market competition if the banks themselves are subject to a risk-shifting problem, as in our paper. In contrast, a model where only the banks' borrowers are subject to a moral hazard problem (as in Boyd and De Nicoló (2005)) is inconsistent with the basic mechanism of our model. There, an increase in the capital requirement *increases* the borrowers' risk-taking due to higher loan rates. Therefore, such a setting is not a useful benchmark for the analysis of capital regulation.

Moreover, the prompt effects of changes in capital regulation on risk-taking are due to the binding capital requirements in our model. In practice, banks tend to hold more than the required capital. If these additional capital buffers remain constant after the change in the capital regulation, the analysis is unchanged. However, as has been argued by Jokivuolle and Peura (2001), the IRB approach tends to increase the volatility of capital requirements, which may induce banks to raise their buffers after switching to the IRB approach. Then the benefits from the IRB approach would diminish, and so would the competitive distortions. But it is also conceivable that the capital buffers decrease because the banks have more control over how much capital they actually need. Then the effects from our model may even be reinforced.

In reality, banks may react to the new regulation in a number of ways that are not captured by our model. One possibility is bank mergers. The new regulation clearly sets incentives for bank mergers, especially among small banks or between large and small banks. In our model, the merged bank would take the safe project and economize on capital. This would constitute a welfare improvement. But a merger also raises transportation costs and thereby decreases welfare, at least if one of the local branches is closed. Outside of our model, there are a number of additional considerations that make this perspective less desirable. Most importantly, the merged banks may become "too big to fail," which would raise new incentive problems (see Hakenes and Schnabel (2004) for a recent theoretical treatment). Moreover, mergers may reduce competition. So far, empirical work on the U. S. economy has not been able to find any indications that acquisition activity will increase significantly after the introduction of Basel II (see Hannan and Pilloff (2004)).

Alternatively, the small banks may react to the new regulation by cooperating with other banks in their risk management (e. g., by establishing joint rating systems) in order to save on fixed costs. Similarly, the small banks may delegate their risk management to a third party; however, this could give rise to new incentive problems. In both cases, small banks could operate independently, but still benefit from economies of scale. In the context of our model, this would constitute a clear welfare improvement, and it would circumvent many of the disadvantages of bank mergers. However, such solutions will only be possible if the regulators are willing to support cooperation among the small banks, for example, by accepting or even promoting data pooling initiatives. This would allow smaller banks to overcome the problem of deficient historical data. Furthermore, legal restrictions (stemming, for example, from bank secrecy laws) could prevent banks from exchanging sensitive information about their customers with other banks or intermediaries.

Our results have important implications for the provision of loans to SMEs after the implementation of the new accord. If small firms borrow from small banks, our model predicts not only a decrease in bank lending to SMEs, but also a shift to SMEs with riskier projects. Hence, the SMEs with the most efficient projects are bound to loose the most. This effect may be mitigated by the fact that the IRB approach gives preferential treatment to SME loans; this may induce some of the safer SMEs to switch to larger banks. However, the large banks may not be prepared to extend loans based primarily on soft information. In addition, the disparate treatment of small and large banks may raise fairness concerns.

In principle, the adverse effects of the new Basel Accord described in this paper can be mitigated in three ways: first, by lowering the fixed costs of implementing the IRB approach; second, by subsidizing the small banks to enable them to adopt the IRB approach; and third, by enabling smaller banks to exploit the existing economies of scale through cooperation or the use of intermediaries. It may be difficult to lower fixed costs without changing the accord, and without compromising the reliability of the banks' rating systems. A subsidization through public funds is unlikely. However, the fact that the IRB approach sets lower capital requirements for good projects may be seen as an implicit subsidy, aimed to induce banks to adopt the approach. But we suspect that this subsidy may not make a switch profitable for smaller banks. The third solution seems to be easiest to implement. It only requires that the legal foundations for the pooling and exchanging of internal bank data be laid. It remains to be seen whether such a proposal will be able to gain political support. We argued above that the new accord may itself be seen as a manifestation of regulatory capture by the large banks, who appear to be the beneficiaries of the new regulation. They may not give up their privileges easily.

A Appendix

Proof of Proposition 1: We consider the border between regions $1 \cup 2 \cup 3$ and $4 \cup 5$ (the proof for the border between regimes 4 and 5 proceeds analogously). At the border, $\sigma = \sigma_S^{\text{crit}}$ and small banks are just indifferent between the safe project (and the critical rate r^{crit}) and the risky project (and a rate *above* r^{crit}). The large bank's interest rate is r^{crit} in both cases. Expected profits of small banks are

$$\Pi_S^{\text{Reg. 3}} = \left(\frac{D_S}{n} + \sigma\left(r^{\text{crit}} - r^{\text{crit}}\right)\right)\left(\frac{p_1\, y_1 - \alpha\, r_k}{1-\alpha} - r^{\text{crit}}\right)$$

$$\begin{aligned}
&= \frac{D_S}{n}\Big(\frac{p_1\,y_1-\alpha\,r_k}{1-\alpha}-r^{\text{crit}}\Big),\\
\Pi_S^{\text{Reg.}\,4} &= \Big(\frac{D_S}{n}+\sigma\,(r_S-r^{\text{crit}})\Big)\Big(\frac{p_1\,y_1-\alpha\,r_k}{1-\alpha}-r^{\text{crit}}\Big)\\
&= \frac{1}{4\,\sigma}\,\left(\frac{D_S}{n}+\sigma\left[\frac{p_2\,y_2-\alpha\,r_k}{1-\alpha}-r^{\text{crit}}\right]\right)^2.
\end{aligned}$$

The function $\sigma_S^{\text{crit}}(\alpha)$ is defined by $\Pi_S^{\text{Reg.}\,3}=\Pi_S^{\text{Reg.}\,4}$. Solving for σ, we get

$$\begin{aligned}
\sigma_S^{\text{crit}} &= \frac{(p_1-p_2)\,(1-\alpha)\,D_S/n}{\big(\sqrt{A}-\sqrt{B}\big)^2}, \quad \text{with}\\
A &= (p_1-p_2)\,(p_1\,y_1-p_2\,y_2), \quad \text{and}\\
B &= p_1\,p_2\,(y_2-y_1)-(p_1-p_2)\,\alpha\,r_k.
\end{aligned}$$

Clearly, σ_S^{crit} is always nonnegative, and it goes to infinity if $A=B$, hence if

$$\alpha=\alpha_\infty:=\frac{p_1^2\,y_1-2\,p_1\,p_2\,y_2+p_2^2\,y_2}{(p_2-p_1)\,r_k}.$$

For larger α, the algebraical solution is economically meaningless. This can be seen from Figure 4, where the thick curve is the inverse of σ_S^{crit} as a function of α. As $\alpha\to\alpha_\infty$, the curve goes to infinity. If the thick curve reappeared in the plot from the right, the curve would have to cross the borders between regimes 1, 2 and 3, which does not make sense economically.

Hence the proof is complete if we can show that the slope of σ_S^{crit} does not change its sign between zero and the pole. One can show that the derivative of σ_S^{crit} with respect to α is never equal to zero. Consequently, σ_S^{crit} rises monotonously in α, until it reaches the pole at α_∞. ■

Proof of Remark 1: Proposition 1 refers only to the parameter σ. The remark implies that a similar statement applies to all other parameters. Only for $\sigma\le\sigma_S^{\text{crit}}$ do all banks take the safe project. Therefore, the monotonic increase in $\sigma_S^{\text{crit}}(\alpha)$ means that the set of σ's where all banks take the safe project grows for rising α, given the other parameters. More formally, let $\mathbf{P}$ summarize all exogenous parameters except σ and α, and let $\mathcal{S}$ denote the set of parameters where all banks take the safe project in equilibrium. Then Proposition 1 implies that

$$(\alpha_1,\mathbf{P},\sigma)\in\mathcal{S}\implies(\alpha_2,\mathbf{P},\sigma)\in\mathcal{S}\quad\text{for }\alpha_2>\alpha_1.$$

This statement is symmetric with respect to all exogenous parameters. Therefore, one can state more generally that an increase in α weakly reduces the set of (all) parameters for which at least one type of bank chooses the risky project. An analogous argument holds for Propositions 2 and 3. ■

Proof of Proposition 2: An increase in $\Delta\beta$ can be due to either a decrease in β_1 or an increase in β_2, or both. Hence, to show that $\mathrm{d}\sigma_S^{\text{crit}}/\mathrm{d}\Delta\beta>0$, it is sufficient to show that $\mathrm{d}\sigma_S^{\text{crit}}/\mathrm{d}\beta_1<0$ and $\mathrm{d}\sigma_S^{\text{crit}}/\mathrm{d}\beta_2>0$. We present the proof for $\mathrm{d}\sigma_S^{\text{crit}}/\mathrm{d}\beta_2>0$; that for $\mathrm{d}\sigma_S^{\text{crit}}/\mathrm{d}\beta_1<0$ is analogous.

The switch between regimes 3 and 4 is again defined by the indifference of small banks between safe and risky projects (the proof for the borders between regimes 4 and 5 proceeds analogously), hence

$$\begin{aligned}\Pi_S^{\text{Reg. 3}} &= \frac{D_S}{n}\left(\frac{p_1\,y_1-\beta_1\,r_k}{1-\beta_1}-\dot{r}^{\text{crit}}\right)-C \stackrel{!}{=}\\ \Pi_S^{\text{Reg. 4}} &= \frac{1}{4\,\sigma_S^{\text{crit}}}\left(\frac{D_S}{n}+\sigma_S^{\text{crit}}\left(\frac{p_2\,y_2-\beta_2\,r_k}{1-\beta_2}-\dot{r}^{\text{crit}}\right)\right)^2-C.\end{aligned}$$

This equality defines an implicit relation $\sigma_S^{\text{crit}}(\beta_2)$. Because σ_S^{crit} also depends on $\dot{r}^{\text{crit}}$, which in turn depends on β_2, one can write

$$\frac{\mathrm{d}\sigma_S^{\text{crit}}}{\mathrm{d}\beta_2}=\frac{\partial\sigma_S^{\text{crit}}}{\partial\beta_2}+\frac{\partial\sigma_S^{\text{crit}}}{\partial\dot{r}^{\text{crit}}}\,\frac{\partial\dot{r}^{\text{crit}}}{\partial\beta_2}.$$

As stated in the main text, $\partial\dot{r}^{\text{crit}}/\partial\beta_2>0$. Therefore, it remains to be shown that $\partial\sigma_S^{\text{crit}}/\partial\beta_2>0$ (a rise in β_2 leads to a rise in σ_S^{crit} if $\dot{r}^{\text{crit}}$ is held constant) and $\partial\sigma_S^{\text{crit}}/\partial\dot{r}^{\text{crit}}>0$ (a rise in $\dot{r}^{\text{crit}}$ leads to a rise in σ_S^{crit} if β_2 is kept constant).

We first show that $\partial\sigma_S^{\text{crit}}/\partial\beta_2>0$, treating $\dot{r}^{\text{crit}}$ as a constant. The implicit function theorem yields

$$\frac{\partial\sigma_S^{\text{crit}}}{\partial\beta_2}=-\frac{\partial\Pi_S^{\text{Reg. 3}}/\partial\beta_2-\partial\Pi_S^{\text{Reg. 4}}/\partial\beta_2}{\partial\Pi_S^{\text{Reg. 3}}/\partial\sigma_S^{\text{crit}}-\partial\Pi_S^{\text{Reg. 4}}/\partial\sigma_S^{\text{crit}}}=-\frac{\partial\Pi_S^{\text{Reg. 4}}/\partial\beta_2}{\partial\Pi_S^{\text{Reg. 4}}/\partial\sigma_S^{\text{crit}}}.$$

$\Pi_S^{\text{Reg. 4}}$ decreases in β_2 because $\Pi_S^{\text{Reg. 4}}$ rises in $\Phi:=\frac{p_2\,y_2-\beta_2\,r_k}{1-\beta_2}-\dot{r}^{\text{crit}}$, which in turn decreases in β_2 (because $r_k>p_2\,y_2$). Furthermore, $\Pi_S^{\text{Reg. 4}}$ increases in σ_S^{crit} (because it increases in σ, for constant $\dot{r}^{\text{crit}}$). Otherwise, it could not have been optimal for the small banks to choose $\dot{r}^{\text{crit}}$ for σ below σ_S^{crit}. This proves that $\partial\sigma_S^{\text{crit}}/\partial\beta_2>0$.

Now we show that $\partial\sigma_S^{\text{crit}}/\partial\dot{r}^{\text{crit}}>0$. Using again the implicit function theorem,

$$\frac{\partial\sigma_S^{\text{crit}}}{\partial\dot{r}^{\text{crit}}}=-\frac{\partial\Pi_S^{\text{Reg. 3}}/\partial\dot{r}^{\text{crit}}-\partial\Pi_S^{\text{Reg. 4}}/\partial\dot{r}^{\text{crit}}}{\partial\Pi_S^{\text{Reg. 3}}/\partial\sigma_S^{\text{crit}}-\partial\Pi_S^{\text{Reg. 4}}/\partial\sigma_S^{\text{crit}}}=\frac{\partial\Pi_S^{\text{Reg. 3}}/\partial\dot{r}^{\text{crit}}-\partial\Pi_S^{\text{Reg. 4}}/\partial\dot{r}^{\text{crit}}}{\partial\Pi_S^{\text{Reg. 4}}/\partial\sigma_S^{\text{crit}}}.$$

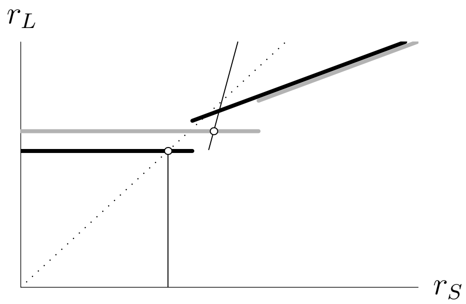
$\partial\Pi_S^{\text{Reg. 3}}/\partial\dot{r}^{\text{crit}}=-D_S/n$ and $\partial\Pi_S^{\text{Reg. 4}}/\partial\dot{r}^{\text{crit}}=-(D_S/n+\Phi\,\sigma_S^{\text{crit}})/2$ with Φ as defined above; hence $\partial\Pi_S^{\text{Reg. 3}}/\partial\dot{r}^{\text{crit}}-\partial\Pi_S^{\text{Reg. 4}}/\partial\dot{r}^{\text{crit}}=-(D_S/n-\Phi\,\sigma_S^{\text{crit}})/2$. Furthermore,

$$\partial\Pi_S^{\text{Reg. 4}}/\partial\sigma_S^{\text{crit}}=\frac{\Phi}{2\,\sigma_S^{\text{crit}}}\left(\frac{D_S}{n}+\Phi\,\sigma_S^{\text{crit}}\right)-\frac{1}{4\,{\sigma_S^{\text{crit}}}^2}\left(\frac{D_S}{n}+\Phi\,\sigma_S^{\text{crit}}\right)^2.$$

This term is equal to zero for $\Phi=\frac{D_S}{n\,\sigma_S^{\text{crit}}}$ (the other zero is for negative Φ). For smaller Φ, the term is negative; for larger Φ, it is positive. For smaller Φ, the term $\partial\Pi_S^{\text{Reg. 3}}/\partial\dot{r}^{\text{crit}}-\partial\Pi_S^{\text{Reg. 4}}/\partial\dot{r}^{\text{crit}}$ from above is also negative, and vice versa. As a result, the numerator and denominator of $\partial\sigma_S^{\text{crit}}/\partial\dot{r}^{\text{crit}}$ always have the same signs. This proves that $\partial\sigma_S^{\text{crit}}/\partial\dot{r}^{\text{crit}}>0$, and completes the proof of the proposition. ■

Proof of Proposition 3: For the proof, we build on the intuition delivered by Figure 7. Black curves denote the reaction functions of small and large banks under

Figure 7: Reaction Functions Near the Critical α



Thin lines are reaction functions by small banks; thick lines those of large banks. Black lines denote the standardized approach; gray lines the IRB approach. Under the chosen parameter constellation, the kinks occur for negative deposit rates.

the old regulatory framework, i. e., all banks use the standardized approach. Assume that α is set in a such way that the equilibrium is close to the border between regimes 3 and 4. In other words, in equilibrium, small banks are individually indifferent between the critical deposit rate r^{crit} and a higher rate (which would signal the risky project). We want to argue that an increase in $\Delta\beta$ then leads to a switch to regime 4. In Figure 7, the equilibrium is given by the white dot to the left. Here, indeed, the equilibrium r_L is low enough to ensure that small banks offer r^{crit} and take the safe project. Also, the large bank offers r^{crit}. However, it has some "reserves": Even if small banks raised deposit rates, the large bank would not react by raising rates, too (in the figure, the reaction function of the large bank "oversteps" the critical point).

We assumed that a switch to the IRB approach is profitable only for the large bank. As a result, the large bank implements the IRB approach, and the critical deposit rate for the large bank rises from r^{crit} to $\dot{r}^{\text{crit}}$. The large bank raises deposit rates. Consequently, small banks now prefer to offer a higher deposit rate (and thus to signal the risky project). Before the IRB approach was introduced, all banks took the safe project; now all small banks take the risky project. The aggregate deposit volume remains unchanged, hence aggregate risk in the economy has increased.

There are two reasons why small banks may be indifferent between r^{crit} and a higher rate, but the situation may still be different from that in Figure 7. First, small and large banks may be so asymmetric that, at the point at which small banks are indifferent, the large bank offers a rate below r^{crit} (regime 2). Taking the derivative of (7) with respect to α, one proves that, for given r_S, deposit rates of the large bank rise if regulation for large banks softens. As before, this induces the small banks to raise rates and pick the risky project.

Second, banks may be so symmetric, and the IRB approach so close to the standardized approach ($\beta_1 \approx \alpha \approx \beta_2$), that introducing the IRB approach at the large bank, and the ensuing upward swing in market rates will also induce the large bank to take the risky project. This, as already discussed, leads to a contradiction, because large banks would not have implemented the IRB approach in the first place.

Up to now, we have considered only marginal increases in $\Delta\beta$. We now look at a discrete transition from the standardized to the IRB approach. The standardized approach has $\Delta\beta = 0$, the IRB approach has $\Delta\beta > 0$. This can be thought of as a continuous series of marginal increases in $\Delta\beta$. Then if the equilibrium is originally in regimes 1, 2 or 3, it can either stay in these regimes, switch among them (which does not alter aggregate risk-taking), or switch to regime 4 (regime 5 is not possible under the optional IRB approach). Above, in this proof, we have shown that the opposite, a switch from 4 to 3 (and possibly further to 2 or 1), cannot occur in reaction to an increase in $\Delta\beta$. Hence, indeed, the range of σ under which the risky project is chosen is extended. ■

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