



Jukka Vauhkonen

# Bank safety under Basel II capital requirements



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The views expressed in this paper are those of the author and do not necessarily reflect the views of the Bank of Finland.

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# Bank safety under Basel II capital requirements

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## Abstract

We consider the impact of mandatory information disclosure on bank safety in a spatial model of banking competition in which a bank's probability of success depends on the quality of its risk measurement and management systems. Under Basel II capital requirements, this quality is either fully or partially disclosed to market participants by the Pillar 3 disclosures. We show that, under stringent Pillar 3 disclosure requirements, banks' equilibrium probability of success and total welfare may be higher under a simple Basel II standardized approach than under the more sophisticated internal ratings-based (IRB) approach.

Keywords: Basel II, capital requirements, information disclosure, market discipline, moral hazard

JEL classification numbers: D43, D82, G14, G21, G28

# Basel II -vakavaraisuusvaatimusten vaikutus pankkien riskillisyyteen

Suomen Pankin keskustelualoitteita 29/2009

Jukka Vauhkonen  
Rahapolitiikka- ja tutkimusosasto

## Tiivistelmä

Pankkien uusi Baselin komitean suosituksiin perustuva vakavaraisuussäännöstö eli Basel II perustuu kolmeen toisiaan täydentävään ns. pilariin. Valtaosassa Basel II:n taloudellisia vaikutuksia koskevista tutkimuksista keskitytään pilarin 1, eli vähimmäispääomavaatimuksen laskentaa koskevien säännösten vaikutusten arviointiin. Tässä työssä sen sijaan tarkastellaan pilarin 1 ja pankkien julkistamisvaatimuksia koskevan pilarin 3 yhteisvaikutusta pankkien riskinottokannustimiin epätäydellisen pankkikilpailun mallissa, jossa pankin vanhat osakkeenomistajat, ns. sisäpiiriläiset, johtavat pankkia ja maksimoivat omaa hyötyään. Mallissa pääomavaatimusten tavoitteena on kohdistaa pankin epäonnistuneen riskinoton kustannuksia osakkeenomistajille ja siten lieventää täysimääräisen talletussuojan vääristämiä pankkien riskinottokannustimia. Mallissa osoitetaan, että tämä pääomavaatimusten positiivinen ns. capital-at-risk-kannustinvaikutus voi olla suurempi Basel II:n luottoriskin standardimenetelmässä kuin Basel II:n sisäisten luokitusten (IRB) menetelmässä silloin, kun pilarin 3 edellyttämät tiedot antavat pankin riskillisyydestä tarkan kuvan, ja pienempi silloin, kun ne antavat riskillisyydestä epätarkan kuvan.

Avainsanat: Basel II, vakavaraisuuden sääntely, julkistamisvaatimukset, markkinakuri, moraalikato

JEL-luokittelu: D43, D82, G14, G21, G28

# Contents

Abstract.....	3
Tiivistelmä (abstract in Finnish).....	4
<b>1 Introduction.....</b>	<b>7</b>
<b>2 The model.....</b>	<b>11</b>
<b>3 Benchmark: no regulation and disclosure.....</b>	<b>13</b>
<b>4 Flat capital requirements without information disclosure: Basel I.....</b>	<b>13</b>
<b>5 Flat capital requirements with information disclosure: Basel II standardized approach.....</b>	<b>16</b>
<b>6 Internal ratings-based (IRB) approach.....</b>	<b>18</b>
<b>7 Partial disclosure.....</b>	<b>21</b>
<b>8 Discussion: Multiple assets.....</b>	<b>23</b>
<b>9 Concluding comments.....</b>	<b>24</b>
References.....	26
Appendix.....	29





# 1 Introduction

The financial crisis that started in the summer of 2007 revealed serious shortcomings in financial institutions' risk management and in the transparency of their actions. Alarming, risk management badly failed even in some of the biggest and most sophisticated financial institutions (see eg Banziger, 2008). The lack of transparency of financial institutions' exposures to securitized instruments and off-balance sheet vehicles, in turn, contributed to the severity of the crisis (see eg Gorton, 2008). Thereby, a major lesson of the crisis is that financial institutions' risk management and the disclosure of their on and off balance risks must be improved (see eg FSF, 2008, and G20, 2008).

Banks' new Basel II capital requirements are widely believed to be a step forward in this respect, as the Pillar 3 of the new framework – market discipline – requires banks to disclose detailed information on their risk profile, capital adequacy, and risk assessment processes (Basel Committee, 2006a).<sup>1</sup> Ideally, Pillar 3 disclosures can help investors in identifying changes in banks' conditions and incorporating these changes into banks' security prices. This, in turn, is supposed to enhance banks' incentives to behave prudently and improve their risk management.

Despite the potential importance of the Pillar 3, most of the academic literature on Basel II concentrates only on the effects of minimum capital ratios, that is, Pillar 1 of the new framework (for exceptions, see Décamps et al, 2004, and Rochet, 2004). In this paper, we examine the combined effect of the Pillar 1 minimum capital requirements and Pillar 3 disclosure requirements.<sup>2</sup> We show that the disclosure requirements may indeed enhance the effectiveness of minimum capital ratios by increasing banks' incentives to improve the quality of their risk measurement and management systems. Somewhat surprisingly, this positive impact may be stronger under the simple Basel II standardized approach than under the more sophisticated internal ratings-based (IRB) approach. This result is most likely to hold, if the Pillar 3 disclosure requirements are relatively stringent and if the regulatory qualifying criteria for the use of the IRB approach are relatively lax.

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<sup>1</sup> The Pillar 3 disclosure requirements include both quantitative and qualitative disclosures, for example, on banks' capital structure; the risks to which banks are exposed and the techniques that banks use to identify, measure, monitor and control those risks; risk management objectives and policies; geographic, industry and counterparty type distribution of exposures; structure of internal ratings system and relation between internal and external ratings; description of the internal ratings process; information about risk parameters such as probabilities of default (PD) and loss given default (LGD) in a portfolio level; the process for managing and recognizing credit risk mitigation, and the bank's role in the securitization process and the amount of securitized exposures. Most of the disclosures should be made on a semi-annual basis (see Basel Committee, 2006a, Part 4).

<sup>2</sup> The Pillar 2 of the Basel II framework, the supervisory review process, is indirectly taken into account in our specification of the IRB approach, see below.

We consider a Salop-type spatial model of imperfect banking competition with four types of agents: banks' inside and outside shareholders (insiders and outsiders), depositors and the regulator (supervisor). Insiders, who are either owner-managers or old shareholders and who maximize their own payoffs, make the decisions in the banks. Banks are funded by fully insured deposits and capital. They compete for deposits by setting their deposit rates and have market power as depositors must incur transportation costs when travelling to a bank.

Banks invest funds in a single loan (portfolio). A bank's probability of success depends on the quality of its risk measurement and management systems (for brevity, the 'quality of risk management' or just 'quality'), chosen by the bank's insiders. Without common disclosure criteria such as the Pillar 3, this quality is unobservable to market participants, as a voluntary disclosure is assumed to be infeasible. Furthermore, in the absence of disclosure and capital requirements, the equilibrium quality of risk management is lower than the first-best as insiders do not reap the full return of their effort.

The regulator's aim is to alleviate this moral hazard problem by requiring banks to raise capital. By setting capital requirements, the regulator attempts to increase banks' shareholders' losses in case of default and induce banks to reduce the probability of failure by improving their risk management systems. In the above set-up, we model three different regulatory capital approaches for credit risk – the previous Basel I capital requirements and the two options of the new Basel II capital requirements, the standardized approach (SA) and Basel II internal ratings-based (IRB) approach – in a stylized fashion and examine their impacts on the equilibrium quality of banks' risk management.<sup>3</sup>

On the basis of Besanko and Kanatas (1996) and Hellmann et al (2000), for example, capital requirements may potentially influence bank insiders' incentives through two effects: the *dilution effect*<sup>4</sup> and the *capital at risk effect*. The dilution effect is typically negative. Capital requirements force banks to raise new capital, which erodes bank insiders' payoffs and reduces their incentives to improve the quality of risk management. On the other hand, as shown by Hellmann et al (2000) and others, the larger is a bank's capital-to-deposit ratio, the larger is the downside risk that bank insiders bear. This capital at risk effect tends to improve insiders' incentives. It also plays a key role in our paper.

In our set-up, Basel I is, as usual, characterized by a flat-rate minimum regulatory capital-to-deposits ratio. In addition, we assume that under Basel I, the quality of banks' risk management is unobservable to outsiders. Given these

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<sup>3</sup> A large number of countries have already adopted the Basel II framework. The EU's capital requirement directives (CRD) were adapted progressively during 2007–2008. However, for example the US is still in the process of adopting the framework.

<sup>4</sup> This dilution effect is, essentially, equivalent to the franchise value effect studied in multi-period settings by Hellmann et al (2000) and Repullo (2004). However, in our static environment, we prefer to use the term dilution effect.

assumptions, we show that Basel I has *no* effect on banks' equilibrium probability of success relative to the benchmark of no regulation, as neither the dilution effect nor the capital at risk effect are at work. Similarly as in Repullo (2004), the dilution effect does not operate, since the cost of capital requirement is fully transferred to depositors. The capital at risk effect does not operate, since insiders have no own capital at stake and as the risk of an individual bank is unobservable to outsiders. Thus, our results suggest that flat-rate capital requirements, such as Basel I, can be fairly ineffective in improving bank safety, if there are serious conflicts of interests between banks' insiders and other equityholders and if insiders' actions are not transparent to market participants.

Next, we examine a scenario in which all banks are required to use the Basel II standardized approach, which can be regarded as a refinement of the Basel I approach. The difference between the approaches in our set-up is that under the standardized approach, the quality of banks' risk management systems is made either fully or partially observable by the Basel II Pillar 3 disclosures. We show that by making the risk of an individual bank observable, the disclosure affects the bank's cost of capital and increases the equilibrium quality of banks' risk management systems. Thus, this result supports the argument by Gordy and Howells (2006, p. 397) that the ultimate success of Pillar 1 standards rests on how well the Pillar 3 functions.

Then, we examine the scenario in which all banks must choose the IRB approach. We consider a reduced version of the IRB approach by modeling three key elements of the IRB approach. First, to be eligible to enter into and use the IRB approach a bank has to satisfy an extensive set of qualifying requirements. In our model, these requirements define the *minimum quality* of banks' risk management systems under the IRB approach. Second, the minimum capital requirement for banks is lower under the IRB approach than under the standardized approach.<sup>5</sup> Third, similarly as under the Basel II standardized approach, the quality of banks' risk management systems is made either fully or partially observable by the Pillar 3 disclosures.<sup>6</sup>

Given these assumptions, our key finding is that the superiority between the IRB approach and the Basel II standardized approach in improving bank safety depends crucially on the stringency of the Pillar 3 disclosure requirements and the IRB qualifying requirements. We show that under stringent Pillar 3 disclosure requirements and lax IRB qualifying requirements, the equilibrium quality of banks' risk management systems is higher and thus their equilibrium probability

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<sup>5</sup> The Basel Committee's quantitative impact studies indeed suggest that the average minimum capital requirements under the IRB approach are lower than those under the standardized approach, see [www.bis.org](http://www.bis.org).

<sup>6</sup> The best-known difference between the IRB approach and the standardized approach is that in the former banks can use their own internal estimates of risk components to compute capital charges for their exposures. There is already a vast literature on the potential impacts of this difference. For a recent survey, see VanHoose (2007).

of default lower under the Basel II standardized approach than under the IRB approach. Under lax Pillar 3 disclosure requirements, in turn, the IRB approach generates higher bank safety in the equilibrium than the standardized approach.

Our model is largely based on Cordella and Levy Yeyati (2002), who study the effects of market discipline and deposit insurance on bank risk-taking. We abstract deposit insurance but introduce bank insiders and outsiders as well as capital requirements into their set-up. Our model is also related to the models by Hellmann et al (2000) and Repullo (2004) on the effects of capital regulation on bank risk-taking. Our model differs from their models in that we examine the combined effect of capital requirements and disclosure. In addition, in our model the moral hazard stems from effort aversion whereas in their models it stems from asset substitution. Besanko and Kanatas (1996), similarly like us, examine the effects of capital regulation on bank safety in a model with bank insiders and outside investors. In their model, capital requirements may worsen the effort-aversion moral hazard problem, as outsiders' capital injection dilutes insiders' expected surplus from successful projects. In our model with explicitly specified competition in deposit markets, there is no such negative dilution effect, as the cost of capital requirements is fully passed to depositors.

The present paper examines the disciplining role of outside equityholders on banks. There are several papers which analyse the disciplining role of *creditors* (see eg Calomiris and Kahn, 1991, and Diamond and Rajan, 2001). In most of these studies, banks' creditors can punish banks by withdrawing their demandable deposits or by not rolling their short-term loans, if they are not satisfied with the bank's performance. Thus, these models examine the impact of interim or the ex post market discipline on banks. In Blum (2002), similarly as in this paper, market discipline operates *ex ante* through the pricing of banks' funding. He examines the impact of subordinated debt on banks' risk-taking, and shows that subordinated debt may lead to an increase in risk, if a bank cannot credibly commit to a given level of risk. In our model the commitment is not a problem, as bank insiders choose their risk-taking (the quality of risk management systems) before the funds are raised. Instead, in our model the severity of the moral hazard problem depends on the regulatory choices and the degree of transparency on banks' actions.

Finally, there is a relatively large literature on the effects of mandatory disclosure requirements on bank risk taking and financial stability (for a survey, see Frolov, 2007).<sup>7</sup> This literature suggests that the effects of mandatory disclosures may not always be positive. We, however, focus on the beneficial effects of the increased transparency and extend the literature on mandatory disclosure requirements by relating our analysis explicitly to the new Basel II framework.

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<sup>7</sup> For empirical research on how the market prices of bank liabilities react to information about bank risk and to what degree does market discipline actually affect bank behavior, see eg. Flannery (1998) and Nier and Baumann (2006).

## 2 The model

Consider a spatial competition model of banking with four sets of risk neutral agents: bank insiders, outside investors, depositors and a bank regulator (supervisor). There are  $n \geq 3$  identical banks indexed by  $i = 1, \dots, n$ , which are symmetrically distributed around a unit circle. Banks are run by insiders, who maximize their utility. Banks invest funds in a single loan (portfolio) with a gross return  $R$ ,  $1 < R < 2$ , per a unit of investment, if it succeeds. If the loan fails, the return is 0, in which case the bank goes bankrupt. The probability that the loan will be repaid is equal to the quality of the bank's risk management systems  $q_i \in [0, 1]$ , chosen by the bank's insiders at a non-monetary private cost  $q_i^2$ .<sup>8,9</sup>

Banks compete for funds in imperfectly competitive deposit markets by offering depositors a (gross) deposit rate,  $r_i$ ,  $i = 1, \dots, n$ ,  $r_i \in [1, R]$ . There is a continuum of depositors uniformly distributed along a unit circle. Each depositor is endowed with a unit of funds that he can invest either in bank deposits by incurring a transportation cost  $\mu$  per a unit of distance or in an outside asset. The total volume of deposits is normalised to 1 and the return of the outside asset to zero. Deposits are fully insured with zero deposit insurance premia. Therefore, when choosing a bank in which to deposit, a depositor is only interested in the offered deposit rates and in the distance between him and the two adjacent banks.

The supply of deposits for bank  $i$  is (for a derivation, see eg Repullo, 2004)

$$D_i(r_i, r) = \frac{1}{n} + \frac{r_i - r}{\mu} \quad (2.1)$$

where  $r$  denotes the common deposit rate of all other banks. In a symmetric equilibrium  $r_i = r$ , and each bank's share of deposits is  $1/n$ .

At  $t = 0$  the regulator may require banks to hold at least  $k_f D_i$  (or  $k_{IRB} D_i$ ) units of capital, where  $k_f$  is the flat minimum required capital-to-deposit ratio under the Basel I and Basel II standardized approaches and  $k_{IRB}$  is the minimum required capital-to-deposit ratio under the IRB approach.<sup>10</sup> Prior to  $t = 0$  banks have no

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<sup>8</sup> This is a reduced way to capturing the fact that the quality of a bank's risk measurement and management systems affects the bank's riskiness. When a bank's insiders put more effort in improving risk management, the bank improves its ability to select high-quality customers, to use risk mitigation techniques, to design and enforce financial contracts etc., which reduce its probability of failure.

<sup>9</sup> The assumption  $C(q_i) = q_i^2$  together with the assumption  $1 < R < 2$  ensures that, at an equilibrium,  $q < 1$ .

<sup>10</sup> Actually, Basel I and Basel II capital requirements are proportional to a bank's (risk-weighted) assets, not to its deposits. In our model, however, assets are equal to the deposits. Notice also that in our set-up the minimum capital-to-deposit ratios (or capital-to-asset ratios) are essentially similar to the leverage ratio restrictions. For a model with both leverage rate restrictions and risk-based capital requirements, see Blum (2008).

capital for regulatory capital purposes. We assume that banks' initial capital, provided by inside shareholders, is so small that it can be assumed to be 0. Insiders have no more funds, so they must raise the capital from outsiders to satisfy the capital requirement. Outsiders' required expected (gross) rate of return is  $\rho$ . Following Hellmann et al (2000) and Repullo (2004), for example, we assume that  $\rho > R$ , so that capital is costly. The capital must be readily available to cover banks' losses in any circumstances. Therefore, the capital must be invested in the risk-free outside asset.

The timing is the following.

- t=0: The regulator sets the regulatory regime: no regulation, Basel I, Basel II standardized approach or Basel II IRB approach.
- t=1: Banks set their deposit rates, the amount of capital they wish to raise, and the quality of their risk management systems.
- t=2: Depositors choose the bank in which to deposit.
- t=3: Banks raise the capital.
- t=4: Banks invest funds in the loan (portfolio).
- t=5: Returns are shared between the parties.

In contrast to the most usual assumption, we assume that banks choose the quality of their risk management systems (effort) before they raise the funds. This assumption can be justified by the fact that it takes considerable time and effort from the bank management to build a bank's institution-specific and often very complex risk management systems. Therefore, in our set-up, it is natural to assume that the risk management systems must be in place before banks' apply for funding. The assumption that the capital is raised after deposits, in turn, follows from our assumption that the required capital must be proportional to a bank's deposit base.

All parties observe the regulatory regime, banks' posted deposit rates and banks' desired level of capital. Banks are able to commit to their posted deposit rates, so they cannot renegotiate their rates once depositors have travelled to banks. In the absence of mandatory disclosure requirements (under no regulation and Basel I), market participants (outsiders and depositors) do not observe the quality of banks' risk management systems. A voluntary disclosure by banks is neither possible or is prohibitively costly. Under the Basel II standardized and IRB approaches the Pillar 3 disclosure requirements make the quality of an individual bank's risk management systems either fully (sections 4 to 6) or partially (section 7) observable to market participants.

### 3 Benchmark: no regulation and disclosure

In what follows, we derive banks' equilibrium safety, that is, the equilibrium quality of their risk management systems, under different regulatory regimes and under different assumptions concerning the observability of the quality of the risk management systems.

As a benchmark, consider the problem of bank  $i$ 's insiders in the absence of regulation and disclosure. Assume, for a moment, that banks do not voluntarily hold any capital.<sup>11</sup> Thus, they are funded only with deposits. Given these assumptions, bank  $i$ 's insiders choose the quality of their risk management systems,  $q_i$ , and the deposit rate,  $r_i$ , to maximise

$$\pi_i^B = q_i(R - r_i)D_i - q_i^2 \quad (3.1)$$

where  $D_i$  is given by (2.1).

Taking the first-order conditions, solving for  $q_i$  and  $r_i$ , and assuming symmetry gives the following equilibrium values under the benchmark

$$q_B = \frac{\mu}{2n^2}; r_B = R - \frac{\mu}{n} \quad (3.2)$$

The equilibrium quality of risk management systems under the benchmark is lower than the first-best<sup>12</sup>, as insiders do not reap the full return of their effort. As a result, banks underinvest in the quality of their risk management systems. This provides the rationale for regulation.

### 4 Flat capital requirements without information disclosure: Basel I

To mitigate the moral hazard problem, the regulator requires banks to raise capital. Under Basel I capital requirements, banks are required to hold, at minimum,  $k_f$  units of capital per a unit of deposits. In addition, similarly as under the benchmark, the quality of banks' risk management systems is not disclosed to the public and the voluntary disclosure is not possible or is prohibitively costly.

Banks raise the required capital from competitive capital markets, where investors' (outsiders) required rate of return on their investment is  $\rho$ . Suppose that

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<sup>11</sup> In the following sections, we show that banks indeed never hold any excess capital.

<sup>12</sup> The first-best action  $q_{FB}$  maximizes the social payoffs of the project,  $\pi_i^{FB} = q_i R - q_i^2$ . The first-order condition with respect to  $q_i$  is  $\partial \pi_i^{FB} / \partial q_i = R - 2q_i = 0$  and the first-best quality  $q_{FB} = R/2$ .

bank  $i$  raises  $D_i$  units of deposits with a deposit rate  $r_i$ , and wishes to raise  $k_i D_i$  units of capital. Outsiders provide this capital to the bank if their expected payoffs from the bank's investment project are equal to their required rate of return on their capital injection, that is, if  $S_i^l q_i^e (R - r_i + k_i) D_i = \rho k_i D_i$ , where  $S_i^l$  denotes the proportion of bank  $i$ 's shares allocated to outsiders (the cost of capital) under the Basel I capital requirements. Solving for  $S_i^l$  gives

$$S_i^l(k_i, r_i, q_i^e) = \frac{\rho k_i}{q_i^e (R - r_i + k_i)} \quad (4.1)$$

Note that in the absence of information disclosure, an individual bank's cost of capital is a function of the expected quality of the bank's risk management systems,  $q_i^e$ . Therefore, as the actual quality is not observable, the bank's insiders can choose a low quality without being penalized by an increase in their bank's cost of capital.

In what follows we derive the interior symmetric rational expectations Nash equilibrium<sup>13</sup>, which is defined by qualities  $q = q_1 = \dots = q_n$ ,  $q \in [0, 1]$ , deposit rates  $r = r_1 = \dots = r_n$ ,  $r \in [1, R]$  and capital-to-deposit ratios  $k = k_1 = \dots = k_n$  such that

- (i) outsiders' expectations are fulfilled:  $q_1^e = \dots = q_n^e = q^e = q$
- (ii) each bank's insiders maximize their payoffs  $\pi_i$  at  $(q, r, k)$  when all other banks' insiders choose the equilibrium quality, equilibrium deposit rate and equilibrium capital-to-deposit ratio, that is  $q = \arg \max_{q_i \in [0, 1]} \pi_i(q_i, q, r, k)$ ,  $r = \arg \max_{r \in [0, 1]} \pi_i(r, q, r, k)$ , and  $k = \arg \max_{k_i} \pi_i(k_i, q, r, k)$
- (iii) deposit markets are covered<sup>14</sup>:  $r \geq \underline{r} \equiv 1 + \mu / 2n$
- (iv) banks satisfy the Basel I regulatory capital requirement:  $k \geq k_f$

Given these constraints, the bank  $i$ 's insiders' problem can be written as

$$\text{Max}_{q_i \in [0, 1], r_i \geq \underline{r}, k_i \geq k_f} \{(1 - S_i^l) q_i (R - r_i + k_i) D_i - q_i^2\} \quad (4.2)$$

where  $D_i$  is defined by (2.1) and  $S_i^l$  in (4.1).

<sup>13</sup> The analysis of Matutes and Vives (1996) suggests that outsiders' different possible prior expectations on  $q_i$ ,  $i = 1, \dots, n$  could become self-fulfilling and lead to multiple equilibria. However, to avoid these complexities, we only focus on the interior symmetric rational expectations Nash equilibrium.

<sup>14</sup> Deposit markets are covered, when the depositors in the midpoint of two adjacent banks are indifferent between depositing and investing in the outside asset. Their distance from the nearest bank is  $1/2n$  and their cost of travelling there is  $\mu/2n$ .



First, we show that the constraint  $k_i \geq k_f$  is binding in the equilibrium. Differentiating (4.2) with respect to  $k_i$  and imposing rational expectations gives  $(q - \rho)D_i < 0$ . So, we have a corner solution,  $k_i = k_f$ . This is a natural consequence of the fact that capital is costly,  $\rho > R$ . With costly capital, there is no reason for banks to hold any excess capital in our model.

By differentiating (4.2) with respect to  $q_i$  and  $r_i$ , setting  $k_i = k_f$ , and imposing symmetry and rational expectations, we obtain the first-order conditions which implicitly determine the interior symmetric equilibrium quality and deposit rates (for simplicity, we drop the subscript  $i$ )

$$\frac{\partial \pi_i}{\partial q} = \frac{R - r_i + k_f}{n} - \frac{\rho k_f}{nq} - 2q = 0 \quad (4.3a)$$

$$\frac{\partial \pi_i}{\partial r} = \frac{q(R - r_i + k_f) - \rho k_f}{t} - \frac{q}{n} = 0 \quad (4.3b)$$

By (4.3a) and (4.3b), the equilibrium quality and the deposit rate under the interior symmetric equilibrium are

$$q_i = \frac{\mu}{2n^2}; r_i = R - \frac{\mu}{n} - k_f \left( \frac{2\rho n^2}{\mu} - 1 \right) \quad (4.4)$$

We assume that the parameters of the model are such that we obtain an interior solution for the equilibrium interest rate,  $r_i > \underline{r}$ .<sup>15</sup> Comparing (4.4) to the benchmark quality and deposit rate (3.2) gives now the following result.

**Proposition 1.** The equilibrium quality of banks' risk management systems under the Basel I is equal to and the deposit rate lower than the corresponding equilibrium levels under the benchmark.

Thus, in the absence of information disclosure, Basel I capital requirements have no effect on the quality of banks' risk management. This is because neither the *dilution effect* nor the *capital at risk effect* of capital requirements affects insiders' incentives. The former does not operate, since, as in Repullo (2004), the cost of capital requirements is fully passed to depositors. The latter does not operate, since insiders have no own capital at stake and as outsiders do not observe the quality. As insiders have no own capital at stake, the regulatory capital requirement has no *direct* capital at risk effect on their effort. In addition, as

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<sup>15</sup> That is,  $R - 3\mu/2n - k_f(2\rho n^2/\mu - 1) - 1 > 0$ .

outsiders do not observe the quality of a bank's risk management systems, the capital at risk effect cannot operate indirectly through the price of capital.

## 5 Flat capital requirements with information disclosure: Basel II standardized approach

In the absence of information disclosure, the equilibrium quality of banks' risk management reflects insiders' private incentives to improve these systems. In this section, we assume that under the Basel II standardized approach, the Pillar 3 disclosure requirements make the risk of an individual bank fully observable<sup>16</sup> and thus priced by the market. We show that this increases the equilibrium quality of banks' risk management relative to the Basel I.

In our specification, the only difference between the Basel I and the Basel II standardized approach is that under the latter, the choice of  $q_i$  is made fully public by the Pillar 3 disclosure requirements. The minimum capital requirement, however, remains unchanged.

Replacing expected quality with the actual quality in (4.1) gives an individual bank's cost of capital,  $S_i^{SA}$ , under the Basel II standardized approach

$$S_i^{SA}(k_i, r_i, q_i) = \frac{\rho k_i}{q_i(R - r_i + k_i)} \quad (5.1)$$

Inserting this into (4.2) simplifies the bank  $i$ 's insiders' problem as the following

$$\text{Max}_{q_i \in [0,1], r_i \geq \underline{r}, k \geq k_f} \{ [q_i(R - r_i + k_i) - \rho k_i] D_i - q_i^2 \} \quad (5.2)$$

Differentiating this objective function with respect to  $k_i$  gives  $(q_i - \rho)D_i < 0$ , so, again, we have a corner solution  $k = k_f$ .

In what follows, we concentrate on the interior equilibrium, where the constraint  $r_i \geq \underline{r}$  is not binding. By differentiating (5.2), setting  $k = k_f$  and imposing symmetry, we get the following first-order condition with respect to  $q$

$$\frac{\partial \pi_{SA}}{\partial q} = \frac{(1 + k_f)R - r}{n} - 2q = 0 \quad (5.3)$$

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<sup>16</sup> In section 7, we examine the partial disclosure scenario.

The first-order condition with respect to  $r$  is as under the flat capital requirements (4.3b). From (4.3b) and (5.3), the equilibrium quality  $q_{SA}$  under the Basel II standardized approach is implicitly characterized as

$$G_{SA}(q) \equiv 2(nq)^2 - q\mu - \rho nk_f = 0 \quad (5.4)$$

By comparing the equilibrium quality<sup>17</sup> under the Basel I with that under the Basel II standardized approach, we get the following result.

**Proposition 2.** The equilibrium quality of banks' risk management is higher and the deposit rate lower under the Basel II standardized approach than under the Basel I approach.

**Proof.** Evaluating  $G_{SA}(q)$  at  $q_I = \mu/2n^2$  gives  $G_{SA}(q_I) = -\rho nk_f < 0$ . This, together with the fact that  $\partial G_{SA}/\partial q = 4qn^2 - \mu > 0$  for all  $q > \mu/4n^2$  implies that  $q_{SA} > q_I$ . This, in turn, by (4.3b), implies that  $r_{SA} < r_I$ .

Similarly as in Cordella and Levy Yeyati (2002), the information disclosure fosters banks' quality competition in our model. Because of the disclosure, the bank-specific risk is priced in banks' cost of capital. This improves insiders' incentives to improve the quality of risk management. Notice that the introduction of the information disclosure also improves the social welfare, as it is an increasing function of  $q$  for all  $q \leq q_{FB} = R/2$ .<sup>18</sup> The depositors, however, are worse-off under the Basel II standardized approach than under the Basel I approach, as bank insiders require compensation for their increased cost of effort in the form of lower deposit rates.

Note that an implicit differentiation of (5.4) gives

$$\partial q_{SA} / \partial k_f = - \left( \frac{-\rho n}{4qn^2 - \mu} \right) > 0 \quad (5.5)$$

By Propositions 1 and 2,  $q_{SA} > q_I = \mu/2n^2 > \mu/4n^2$ . Therefore, the above derivative, evaluated at  $q_{SA}$ , is positive.

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<sup>17</sup> The quadratic equation (5.4) has two roots. We can concentrate on the bigger root as the smaller root is negative by the facts that  $\partial G_{SA}(q)/\partial q < 0$ , for  $q < \mu/4n^2$  and  $G_{SA}(0) < 0$ .

<sup>18</sup> A higher quality of banks' risk management systems and the associated lower probability of default implies a higher level of welfare. The equilibrium values of deposit rates, capital levels and the cost of capital do not affect the total welfare, as they only determine how the final payoffs are divided between the risk-neutral parties.

The expression (5.5) implies that under full disclosure, an increase in capital requirements improves bank safety.<sup>19</sup> The reasoning goes as follows. As the capital requirement is always binding in the equilibrium, a stricter capital requirement forces a bank to raise more capital, which increases its capital expenditure (the amount of capital times the cost of capital) for a given quality of the bank's risk management systems. Therefore, a given increase in the quality of a bank's risk managements systems and the associated lower cost of capital produces a bigger absolute reduction in the bank's capital expenditure the higher is the capital requirement. As a result, stricter capital requirements improve insiders' incentives to improve the quality of their banks' risk management systems.

## 6 Internal ratings-based (IRB) approach

Under the Basel II capital regulation, banks are also allowed to use a more sophisticated approach, the internal ratings-based approach (IRB), for calculating their minimum capital requirements for credit risk. In this paper, we focus on two differences between the IRB approach and Basel II standardized approach. First, under the IRB approach, the entry into and ongoing use of the approach requires a bank to meet a detailed set of minimum requirements ('IRB qualifying requirements')<sup>20</sup>. Second, according to Basel Committee's Quantitative Impact Studies, the average minimum required capital levels for those banks who apply the IRB approach are likely to be lower than under the Basel I and Basel II standardized approaches.<sup>21</sup>

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<sup>19</sup> An implicit differentiation of (5.4) gives also the other relevant comparative statics:  $\partial q_{SA}/\partial p > 0$  and  $\partial q_{SA}/\partial \mu > 0$ , for all  $q > \mu/4n^2$ . The sign of  $\partial q_{SA}/\partial n = -(4nq^2 - \rho k_f)/(4qn^2 - \mu)$ , evaluated at  $q = q_{SA}$ , is negative. The proof is available from the author upon request.

<sup>20</sup> These minimum requirements concern (a) composition of minimum requirements, (b) compliance of minimum requirements, (c) rating system design, (d) risk rating system operations, (e) corporate governance and oversight, (f) use of internal ratings, (g) risk quantification, (h) validation of internal estimates (i) supervisory LGD and EAD estimates, (j) requirements for recognition of leasing, (k) supervisory calculation of capital charges for equity exposures, and (l) disclosure requirements (see Basel Committee, 2006a, paragraphs 387–537). Supervisors must, in their Pillar 2 supervisory review process, ensure that these requirements are being met, both as qualifying criteria and on a continuing basis.

<sup>21</sup> According to Basel Committee's (2006b) fifth quantitative impact study, G10 and European banks' minimum required capital levels under the advanced IRB approach (AIRB) would, on average, fall by 7 to 29 per cent relative to the Basel I approach. However, for banks using the IRB approach, there will be a capital floor for at least three years following the implementation of the framework, which limits the amount of reduction in banks' minimum capital requirements.

These assumptions are captured in the following definitions:

**Definition 1.** The IRB qualifying requirement is denoted by the parameter  $\underline{q}$ .

**Definition 2.** The IRB capital requirements are given by a pair  $(\underline{q}, k_{IRB})$  such that

$$\begin{aligned} \text{if } q_i \geq \underline{q}, \text{ then } K &= k_{IRB}, \text{ where } 0 < k_{IRB} < k_f \\ \text{if } q_i < \underline{q}, \text{ then } K &= k_f \end{aligned}$$

This is as a reduced specification of the IRB approach. Only those banks whose risk management systems satisfy  $q_i \geq \underline{q}$  are allowed to enter into and use the IRB approach subject to a supervisory approval. To induce the banks to use the IRB approach, the minimum regulatory capital under the IRB approach is set at a lower level than that under the Basel I and Basel II standardized approaches:  $0 < k_{IRB} < k_f$ . Banks with  $q_i < \underline{q}$  are required to apply the Basel II standardized approach with a minimum capital-to-deposit ratio  $k_f$ .<sup>22</sup>

Consider the determination of the equilibrium quality,  $q_{IRB}$ , of banks' risk management under the IRB approach. Assume that all banks are required to use the IRB and that banks' quality choices,  $q_i$ ,  $i = 1, \dots, n$ , are made fully observable to market participants by the Pillar 3 disclosures. Given these assumptions, the maximization problem for a typical bank  $i$ 's insiders is

$$\text{Max}_{q_i \geq \underline{q}, r_i \geq r, k_i \geq k_{IRB}} \{(1 - S_i^{IRB})q_i(R - r_i + k_i)D_i - q_i^2\} \quad (5.6)$$

where  $S_i^{IRB}(k_i, r_i, q_i)$  denotes the bank  $i$ 's cost of capital under the IRB capital requirements.

Note that under full disclosure, the satisfaction of the IRB qualifying requirement  $q_i \geq \underline{q}$  does not convey any new information to market participants as they fully observe the bank's choice of quality,  $q_i$ . Therefore, the cost of capital for an individual bank is determined similarly as under the Basel II standardized approach. Thus, by (5.1),  $S_i^{IRB}(q_i) = S_i^{SA}(q_i) \equiv \rho k_i / [q_i(R - r_i + k_i)]$ . Inserting this into (5.6) reduces the bank's maximization problem as the following

$$\text{Max}_{q_i \geq \underline{q}, r_i \geq r, k_i \geq k_{IRB}} \{[q_i(R - r_i + k_i) - \rho k_i] - q_i^2\} \quad (5.7)$$

<sup>22</sup> The availability of the two options under the Basel II – the standardized approach and the IRB approach – raises the question of which option banks would rather choose. However, we set this issue aside, as the exact implementation of the framework differs between countries. In some jurisdictions banks have more freedom to choose their preferred option, subject to supervisory approval. In some jurisdictions, for example in the US, the internationally active banks are required to use the IRB approach.

This maximization problem is similar to (5.2) except that in (5.7), there is an additional constraint  $q_i \geq \underline{q}$  and  $k_f$  is replaced by  $k_{IRB}$ . Obviously, the solution to (5.7) is affected strongly on whether the constraint  $q_i \geq \underline{q}$  is binding in the equilibrium or not, or, in other words, whether the IRB qualifying requirement  $\underline{q}$  is ‘stringent’ or ‘lax’. In what follows, we assume that it is lax. That is guaranteed by the following assumption.

**Assumption 1.**  $q_i < \underline{q} < q_{IRB}$ .

The first inequality says that the minimum required quality of banks’ risk management systems under the IRB approach is higher than the equilibrium quality of risk management systems under the Basel I. Otherwise, the IRB qualifying requirement  $\underline{q}$  would always be irrelevant. The latter inequality implies that the constraint  $q_i \geq \underline{q}$  is not binding in the equilibrium under the IRB capital requirements with full disclosure. This assumption can be justified by the fact that the IRB qualifying requirements are based on current industry practices (Basel Committee, 2006a, paragraph 754). Therefore, the satisfaction of the IRB qualifying requirements may not require much additional effort from banks, especially from the most sophisticated ones.

Given Assumption 1, we obtain the implicit solution for the equilibrium quality of banks’ risk management under the IRB approach by following the steps (5.2) to (5.4)

$$G_{IRB}(q) \equiv 2(nq)^2 - q\mu - \rho nk_{IRB} = 0 \quad (5.8)$$

The comparison between the equilibrium qualities of banks’ risk management systems under the two options of the Basel II gives our next proposition.

**Proposition 3.** Under full disclosure and lax IRB qualifying requirements, the equilibrium quality of banks’ risk management systems and the total welfare under the IRB approach are (i) higher than those under the Basel I but (ii) lower than those under the Basel II standardized approach.

**Proof.** The proof of (i) follows along the lines of the proof of Proposition 2. Evaluating  $G_{IRB}(q)$  at  $q_i = \mu/2n^2$  gives  $G_{IRB}(q_i) = -\rho nk_f < 0$ . The rest follows from the fact that  $\partial G_{IRB}/\partial q = 4qn^2 - \mu > 0$ . The proof of (ii) follows from comparing (5.4) and (5.8). Using the assumption that  $k_{IRB} < k_f$ , and the fact that  $\partial G_{IRB}/\partial q > 0$  for all  $q > \mu/4n^2$  implies that  $q_{IRB} < q_{SA}$ .

The reason for the first result is the same as under the previous section. Under the IRB approach, the Pillar 3 disclosures make the quality of banks' risk management systems, and thus banks' riskiness, observable and priced in banks' cost of capital. Because of this effect, bank insiders have greater incentives to improve the quality of their portfolios under the IRB approach than under the Basel I.

The reason for the second result is the following. As the IRB qualifying requirement is assumed to be lax, it does not affect banks' equilibrium safety. The only difference between the Basel II standardized approach and the IRB approach that affects the equilibrium safety is the difference in minimum capital requirements. By assumption, the minimum capital requirement is lower under the IRB approach than under the Basel II standardized approach. Therefore, the disciplinary capital at risk effect of capital requirements is weaker under the IRB approach than under the Basel II standardized approach. Thus, higher capital requirements under the Basel II standardized approach induce bank insiders to improve their banks' risk management systems more than the lower capital requirements under the IRB approach.

The welfare implications follow from the fact that the total welfare is an increasing function of the equilibrium value of  $q$  for  $q \leq R/2$ . Interestingly, the result of the Proposition 3,  $q_{SA} > q_{IRB} > q_I$ , implies, by (4.3b), that  $r_{SA} < r_{IRB} < r_I$ . Thus, the depositors' welfare is the lowest under the Basel II standardized approach, which generates the highest total welfare of the three approaches.

If our assumption that the IRB qualifying requirements are lax is relevant, our results suggest that the IRB approach may, in the worst case, only relax banks' capital requirements without providing them any additional incentives to improve their risk management systems, relative to the Basel II standardized approach. In this scenario, the IRB option, relative to the Basel II standardized approach, provides banks a free lunch with lower minimum capital requirements and non-binding IRB qualifying requirements.

## 7 Partial disclosure

Thus far we have assumed that the quality of banks' risk management systems is either completely non-observable (Basel I) or fully disclosed to the public (Basel II). In this section, we examine the impacts of the Basel II standardized and IRB approaches on bank risk taking under a more realistic scenario of partial public disclosure. In this scenario, the Pillar 3 disclosures improve investors' knowledge of banks' risk management systems but do not make them fully transparent.

We follow Boot and Schmeits (2000) and Hyytinen and Takalo (2002), for example, by assuming that market participants observe the quality,  $q_i$  of a bank's

risk management systems only with a probability  $p$ . With a probability  $(1-p)$  they do not observe the quality, but evaluate it rationally  $E(q_i) = q_i^e$ . We interpret  $p$  as the stringency of the Pillar 3 disclosure requirements. The higher the  $p$ , the more information banks are required to provide to market participants in Pillar 3 on their risk exposures, the structure and organization of their risk management, their policies for hedging and mitigating risk etc. The stricter are these stringency requirements, the more reliably can outsiders evaluate the quality of banks' risk management systems.

Before examining the general case with  $0 \leq p \leq 1$ , it is useful to collect our results of the cases  $p = 0$  and  $p = 1$ . Denote the equilibrium quality of banks' risk management systems under the standardized approach by  $q_{SA}(p)$  and under the IRB approach by  $q_{IRB}(p)$ . The case with  $p = 0$  corresponds in our model to the scenario of no disclosure. Thus, in that case, the Basel II standardized approach is equivalent with the Basel I approach. Therefore, by Proposition 3(i),  $q_{IRB}(0) > q_{SA}(0) = q_i(0)$ . On the other hand, by Proposition 3(ii),  $q_{IRB}(1) < q_{SA}(1)$ . In other words, the IRB approach generates higher equilibrium quality of banks' risk management than the Basel II standardized approach under no disclosure but lower equilibrium quality under full disclosure.

In the light of this result, it is intuitive to expect that, by continuity, there exists a critical level of disclosure  $p^* \in (0,1)$  below which the IRB capital requirements generate a higher quality of banks' risk management and above which the standardized approach generates the higher quality. In the following key proposition of this paper, we show that this is indeed the case.

**Proposition 4.** Under lax Pillar 3 disclosure requirements, the equilibrium quality of banks' risk management and the total welfare is higher under the IRB approach than under the Basel II standardized approach. Under stringent Pillar 3 disclosure requirements, the reverse obtains.

**Proof.** See the Appendix.

Under lax Pillar 3 disclosure requirements (low  $p$ ), insiders' incentives to improve the quality of risk management are low under the Basel II standardized approach, as an increase in their effort is likely to remain unobserved and thus unrewarded by a lower cost of capital. Thus, when  $p$  approaches zero, the equilibrium quality under the standardized approach comes nearer to the equilibrium quality under no regulation. On the other hand, under the IRB approach, the IRB qualifying requirement  $q_i \geq \underline{q}$  becomes binding for low values of  $p$  and thus sets a lower limit to the quality of risk management, which is higher than the corresponding level under no regulation. Under stringent Pillar 3 disclosure requirements (high  $p$ ), an increase in the quality is more likely to be observed and rewarded. As the



increase in the quality is more handsomely rewarded under the Basel II standardized approach (in the form of a bigger reduction in the bank's capital expenditure for a given increase in quality), the equilibrium level of quality under that regime is higher than under the IRB approach.

## 8 Discussion: Multiple assets

In our model, we assume that banks can only invest in a single asset. This assumption may oversimplify the analysis of risk-based capital requirements, as the key element of the IRB capital requirements is that banks are required to hold different amount of capital against assets with different credit risks. In this section, we discuss how the introduction of multiple assets might affect our results.

To examine that, it is useful consider the model of Repullo (2004). He examines the impact of risk-based capital requirements on banks' risk-taking in a model where banks can invest either in a prudent or a risky asset and where the deposit competition is similar as in the present paper. He sets the capital requirement for the prudent asset as zero and for the risky asset as positive and shows that these risk-based capital requirements can ensure the existence of a so-called prudent equilibrium where all banks invest in the prudent asset. Thus, risk-based capital requirements fully resolve the asset substitution moral hazard problem. More generally, Repullo's results suggest that risk-based capital requirements are more effective than flat capital requirements in reducing the asset substitution moral hazard.

The present paper suggests that relatively high flat capital requirements combined with an effective market discipline may be more effective than lower IRB capital requirements in reducing the effort aversion moral hazard. The reason for this result stems from the assumption that the minimum capital requirements under the Basel II standardized approach are higher than those under the IRB approach. Higher capital requirements induce stronger market discipline, which improves banks' incentives to improve the quality of their risk management systems. Importantly, this effect is likely to persist also in a model with multiple assets as the risk-based capital requirements for low risk assets are, by construction, set at a lower level than flat capital requirements.

To summarise, on the basis of Repullo (2004) and the present paper, risk-based capital requirements may to be more effective than flat capital requirements in reducing the asset substitution moral hazard but less effective in reducing the effort aversion moral hazard. Therefore, it is not obvious a priori which regulatory option would generate higher welfare in a model with multiple assets. Analyzing that would require a model in which bank insiders make both a loan portfolio

decision and an effort decision a la Besanko and Kanatas (1996), for example. This remains to be done in the future research.

## 9 Concluding comments

In this paper, we show that an explicit modeling of the information disclosure and the agency problem between banks' insiders and outside investors gives new insights on the effectiveness of different types of regulatory capital requirements. In particular, our results suggest that the effectiveness of regulatory capital requirements in improving bank safety may crucially depend on the stringency of banks' disclosure requirements. Thereby, our results provide support for the Basel Committee's decision to include disclosure requirements in the Basel II framework.

Our results are based on the assumption that the bank capital is initially held by banks' owner-managers or a small number of inside shareholders, who make the decisions in the bank. Capital requirements then force banks' to issue new equity to meet the new standards. This creates a conflict of interest between banks' initial and new shareholders, which shapes our results.

A familiar critique towards owner-manager and insider-outsider models of banking is that large banks' capital is widely held and that the most relevant conflict of interests are between the bank's managers and the outside financiers (depositors and shareholders) and not between different types of financiers. However, we believe that our model is topical as it may illustrate some potential implications of the recent and potentially forthcoming massive bank recapitalizations. As a consequence of the financial crisis that started in the summer of 2007, the US and European financial institutions had raised more than \$900 billion of new capital by the end of 2008 to mitigate their losses (IMF 2009). Essentially, similarly as in our model, banks have been forced to raise new capital to satisfy the minimum capital requirements. In addition, much of this new capital has come from new shareholders, especially from public sources and sovereign wealth funds.

If we believe that the agency problem between banks' old inside shareholders and new shareholders has economic significance, our model implies that banks' cost of new private capital is affected by the degree of transparency of banks' riskiness. This level of transparency depends, inter alia, on the stringency of banks' Basel II Pillar 3 disclosure requirements. If potential investors regard banks' financial information as opaque, they may find it difficult to identify the banks with the best future prospects among those that are seeking new capital. In that case, private capital raising may be difficult even for the least risky banks. In addition, under low transparency, banks' insiders' incentives to improve their

bank's risk management systems might be relatively low, as their effort is unlikely to be adequately rewarded in their bank's cost of new capital. On the other hand, under high transparency and stringent disclosure requirements, the cost of capital better reflect banks' inherent riskiness. This enables better banks to raise cheaper capital and provides bank insiders better incentives to improve their banks' risk management.

In our model, we assume that in the absence of exogenously set disclosure requirements, banks cannot voluntarily disclose information on their level of effort. One may call this assumption into question, as, in reality, banks voluntarily provide an overwhelming amount of information to market participants. However, we assume that in the absence of stringent mandatory disclosure requirements providing a common metric, outsiders cannot easily evaluate banks' risk exposures and the quality of their risk management on the basis of their voluntarily provided financial information.<sup>23</sup> The imposition of Basel II Pillar 3 disclosure requirements, by itself, provides indirect evidence that regulators also take this view. In fact, if a truthful voluntary disclosure was easy, the disclosure requirements would not have been needed in the first place. Most convincingly, the experiences from the current crisis provide indisputable evidence on the opacity of banks' business and risks.

Finally, concerning our notion of market discipline, it is important to distinguish between *ex ante* market discipline and interim market discipline (see eg Freixas and Rochet, 2008, p. 335–336). *Ex ante* market discipline refers to the hypothesis that investors accurately evaluate the risks taken by bank insiders so that they are reflected in the bank's security prices. Interim market discipline, in turn, refers to the process by which investors are able to discipline bank insiders by eg liquidating the bank or by reducing the volume of business they undertake with riskier banks. In our model, market discipline operates through the *ex ante* market discipline, or, more specifically, through the price of equity in the primary equity market. However, new equity offerings are relatively rare. Most often, market discipline operates through the pricing of bank securities in money markets, bond markets and secondary equity markets. An interesting further avenue of research would be to examine the interplay of capital requirements and market discipline when the latter operates through those channels.

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<sup>23</sup> For example, the US authorities make publicly available certain fixed format banking regulatory reports. According to a survey by Federal Reserve Board's Study Group on disclosure (2000), the users of the disclosed information, such as securities analyst, rating agencies and institutional investors, value these reports as they allow direct comparison among banks whereas banks' voluntary disclosures are not so easily comparable.

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## Appendix

**Proof of Proposition 4.** In this proof, we derive the functions  $q_{SA}(p)$  and  $q_{IRB}(p)$  for  $p \in (0,1)$  and show that  $\partial q_{SA}/\partial p > \partial q_{IRB}/\partial p > 0$  for all  $p \in (0,1)$ . This, together with the facts that  $q_{SA}(0) < q_{IRB}(0)$  and  $q_{SA}(1) > q_{IRB}(1)$  guarantees that the curve  $q_{SA}(p)$  crosses the curve  $q_{IRB}(p)$  once from below at some point  $p^* \in (0,1)$ .

Let us first derive the function  $q_{SA}(p)$ . Note first that  $S_i^{SA(p)} \equiv pS_i^{SA} + (1-p)S_i^I$ , where  $S_i^{SA(p)}$  denotes the bank  $i$ 's cost of capital under the standardized approach with partial disclosure and where  $S_i^{SA}$  is given by (5.1) and  $S_i^I$  by (4.1). The insiders' problem is

$$\text{Max}_{q_i \in [0,1], r_i \geq r, k_i \geq k} \{q_i(1 - S_i^{SA(p)})(R - r_i + k_i)D_i - q_i^2\} \quad (\text{A1.1})$$

Inserting the formula of  $S_i^{SA(p)}$  into (A1.1) and differentiating it with respect to  $k_i$  yields  $(q_i - \rho)D_i < 0$  so, similarly as before, we have a corner solution  $k_i = k_f$ . By differentiating (A1.1) with respect to  $q_i$ , setting  $k = k_f$  and imposing symmetry, we get the following first-order condition with respect to  $q$  (we drop the subscript  $i$ )

$$\frac{\partial \pi_{SA(p)}}{\partial q} = \frac{R - r_i + k_f}{n} - \frac{(1-p)\rho k_f}{nq} - 2q = 0 \quad (\text{A1.2})$$

The first-order condition with respect to  $r$  is as under (4.3b). From (A1.2) and (4.3b), we obtain that the equilibrium quality of banks' risk management systems,  $q_{SA(p)}$ , is implicitly characterized by

$$G_{SA(p)}(q) \equiv 2(nq)^2 - q\mu - ppnk_f = 0 \quad (\text{A1.3})$$

By implicit differentiation of (A1.3), we obtain

$$\partial q_{SA(p)} / \partial p = - \left( \frac{-\rho nk_f}{4qn^2 - \mu} \right) > 0, \text{ for all } q > \mu / 4n^2 \quad (\text{A1.4})$$

Now, following the similar steps, derive the function  $q_{IRB}(p)$ . First, note that  $q_{i,IRB}^e(0) = q_{IRB}^e(0) = \underline{q}$ . Thus,  $S_i^{IRB(p)} \equiv pS_i^{IRB(1)} + (1-p)S_i^{IRB(0)}$ , where  $S_i^{IRB(1)} = S_i^\Pi = \rho k_i / [q_i(R - r_i + k_i)]$  and  $S_i^{IRB(0)} = \rho k_i / [\underline{q}(R - r_i + k_i)]$ . Thus, the insiders' problem is

$$\text{Max}_{q_i \geq \underline{q}, r_i \geq r, k_i \geq k_{IRB}} \{q_i(1 - S_i^{IRB(p)})(R - r_i + k_i)D_i - q_i^2\} \quad (\text{A1.5})$$

Inserting the formula of  $S_i^{\text{IRB}(p)}$  into (A1.5) gives

$$\text{Max}_{q_i \geq \underline{q}, r_i \geq \underline{r}, k_i \geq k_{\text{IRB}}} \{q_i [R - r_i + k_i - (1-p)\rho k_i / \underline{q}] - p\rho k_i\} D_i - q_i^2 \quad (\text{A1.5}')$$

Differentiating (A1.5') with respect to  $k_i$  gives  $[q_i - q_i \rho(1-p) / \underline{q} - p\rho] D_i < 0$ , since  $\rho > R$  and  $q_i \geq \underline{q}$ . So, again, we have a corner solution  $k_i = k_{\text{IRB}}$ . Inserting this into (A1.5'), differentiating it with respect to  $q_i$  and  $r_i$  and assuming symmetry gives the following first-order conditions with respect to  $q$  and  $r$  (we drop the subscript  $i$ )

$$\frac{\partial \pi_{\text{IRB}(p)}}{\partial q} = \frac{R - r_i + k_{\text{IRB}}}{n} - \frac{(1-p)\rho k_{\text{IRB}}}{n\underline{q}} - 2q = 0 \quad (\text{A1.6a})$$

$$\frac{\partial \pi_{\text{IRB}(p)}}{\partial r} = \frac{q[R - r_i + k_{\text{IRB}} - (1-p)\rho k_{\text{IRB}} / \underline{q}] - p\rho k_{\text{IRB}}}{\mu} - \frac{q}{n} = 0 \quad (\text{A1.6b})$$

From (A1.6a) and (A1.6b), we obtain that the equilibrium quality of banks' risk management systems,  $q_{\text{IRB}(p)}$ , is implicitly determined by

$$G_{\text{IRB}(p)}(q) \equiv 2(nq)^2 - q\mu - p\rho n k_{\text{IRB}} = 0 \quad (\text{A1.7})$$

An implicit differentiation of (A1.7) gives

$$\partial q_{\text{IRB}(p)} / \partial p = - \left( \frac{-\rho n k_{\text{IRB}}}{4qn^2 - \mu} \right) > 0, \text{ for all } q > \mu / 4n^2 \quad (\text{A1.8})$$

Comparing (A1.4) and (A1.8) and using the fact that  $k_f > k_{\text{IRB}}$  shows that  $\partial q_{\text{SA}} / \partial p > \partial q_{\text{IRB}} / \partial p > 0$ . QED



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