Credit and Capital Markets, 46. Jahrgang, Heft 4, Seiten 439–465
Abhandlungen

Regulation, Credit Risk Transfer with CDS, and Bank Lending*

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Abstract

We integrate Basel II (and III) regulations into the industrial organization approach to banking and analyze the interaction between capital adequacy regulation and credit risk transfer with credit default swaps (CDS) including its effect on lending behavior and risk sensitivity of a risk-neutral bank. CDS contracts may be used to hedge a bank's credit risk exposure at a certain (potentially distorted) price. Regulation is found to induce the risk-neutral bank to behave in a more risk-sensitive way: Compared to a situation without regulation the optimal volume of loans decreases more as the riskiness of loans increases. CDS trading is found to interact with the former effect when regulation accepts CDS as an instrument to mitigate credit risk. Under the substitution approach in Basel II (and III) a risk-neutral bank will over-, fully or under-hedge its total exposure to credit risk conditional on the CDS price being downward biased, unbiased or upward biased. However, the substitution approach weakens the tendency to over-hedge or under-hedge when CDS markets are biased. This promotes the intention of the Basel II (and III) regulations to "strengthen the soundness and stability of banks".

* Paper presented at the 2012 conferences of the European Financial Management Association (EFMA) in Barcelona and the Verein für Socialpolitik in Göttingen, at the 2011 conference of the German Economic Association of Business Administration (GEABA) in Zürich, at the Financial Risks International Forum 2012 in Paris, at the 2011 workshop of the Research Task Force of the Basel Committee on Banking Supervision in Istanbul, and at the Bundesbank Research Seminar in Frankfurt. We would like to thank conference, workshop and seminar participants and in particular Ulrich Krueger, Peter Raupach, Thomas Gehrig, Bent Vale and Nikolaos Papanikolaou for valuable comments and suggestions. The views expressed in this paper represent the authors' personal opinions and do not necessarily reflect the views of the Deutsche Bundesbank or its staff.

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Regulierung, Kreditrisikohandel mittels CDS und Kreditvergabeverhalten von Banken

Zusammenfassung

Das vorliegende Papier betrachtet eine grundsätzlich risikoneutrale Bank, die im Einlagen- und (risikobehafteten) Kreditgeschäft tätig ist, einer Eigenkapitalregulierung unterliegt und über die Möglichkeit des Kreditrisikohandels mittels Credit Default Swaps (CDS) verfügt. Zur Analyse der Interaktion zwischen Eigenkapitalregulierung und Kreditrisikohandel, des Kreditvergabeverhaltens sowie der Risikosensitivität der Bank kommt das industrieökonomische Bankmodell zur Anwendung. Besonderes Augenmerk wird dabei auf die Berücksichtigung der Eigenkapitalregulierung nach Basel II (und III) gelegt. Die Modellanalyse zeigt, dass eine grundsätzlich risikoneutrale Bank in Folge der Eigenkapitalregulierung nach Basel II (und III) risikosensitiv agiert: Im Vergleich zu einer nicht regulierten risikoneutralen Bank sinkt das optimale Volumen riskanter Kredite durch die Regulierung umso stärker, je höher das Risiko des Kreditportfolios ist. Darüber hinaus verdeutlicht die Analyse eine Interaktion des zuvor genannten Effektes mit den Anreizen der Bank, Kreditrisiken mittels CDS-Kontrakten zu handeln. Wenn die Regulierung CDS-Kontrakte als Instrument der Kreditrisikominderung anerkennt – dies ist in Basel II und III der Fall – wird sich eine risikoneutrale Bank auch dann am Risikohandel beteiligen, wenn der CDS-Preis unverzerrt ist, d.h. gerade der erwarteten Ausfallrate entspricht. Aufgrund des Substitutionsansatzes in Basel II (und III) sichert eine risikoneutrale Bank dann im Optimum gerade ihre gesamte Kreditrisikoposition ab. Eine Abweichung des CDS-Preises vom unverzerrten Preis nach unten oder oben führt dagegen zur Über- bzw. Unterabsicherung der gesamten Kreditrisikoposition im Optimum. Der Substitutionsansatz reduziert hierbei allerdings das Ausmaß der Über- bzw. Unterabsicherung und beeinflusst somit das Verhalten einer risikoneutralen Bank in einer Weise, die der generellen Zielsetzung der Baseler Eigenkapitalvorschriften entspricht. Die Bonität und Stabilität der Bank wird positiv beeinflusst, da die Bank infolge der Berücksichtigung des risikomindernden Effektes aus dem Kreditrisikohandel innerhalb der Regulierung weniger extreme Positionen im CDS-Markt einnimmt.

Keywords: Banking, Regulation, Credit Risk
JEL Classification: G21, G28

I. Introduction

There is a wide-spread view that some firms in the financial services industry had taken excessive risks before the onset of the recent banking crisis. Financial innovations enabling credit risk to be sold by the originator of a loan to a third party are suspected of having contributed to this risk taking. A large variety of financial contracts and institutional setups can nowadays be used to trade credit risk. In addition to loan sales and securitizations, credit default swaps (CDS) play a major role. Hedge fund manager George Soros referred to credit default swap contracts as "toxic" and called for banning their use (*Cullen* (2009)).

On the part of the banks, the possibility to transfer credit risk supports the "originate-to-distribute" (OTD) business model. It liberates capital, thereby allowing for a greater volume of loans: "CDSs were created by J.P. Morgan's derivatives group in 1994 to permit a bank to reduce its capital reserve requirement, which is based on a bank's loan portfolio" (*Helm* et al. (2009) 3). At the same time it created new ways for optimizing banks' asset portfolios (*Duffie* (2007)). Banks have been using these opportunities and are therefore the dominant players on both sides of markets for CDS. An increased importance of buying CDS in order to hedge banks' trading has been reported by the British Bankers Association (cf. *Mengle* (2007) 12).

Parallel to the rapid development of credit risk transfer since the middle of the 1990s there has been an ongoing discussion about the role of capital adequacy regulation to influence bank behavior and make banks more robust against shocks, i.e., to "strengthen the soundness and stability of banks" in the usual Basel parlance. Capital adequacy regulation affects the maximum volume of loans a bank can hand out under a given level of capital. Since credit risk transfer liberates capital from regulatory duties, credit risk transfer and capital adequacy regulation interact.

In this environment capital adequacy regulation nowadays may have conflicting effects. While the more efficient use of bank capital generates macroeconomic benefits through more loans and higher growth, it is by no means clear whether the stability of the banking system as a whole benefits or suffers from banks selling credit risk. On the one hand, diversification of risks and spreading risk over a larger number of market participants ought to increase stability. On the other hand, a higher total volume of loans in the economy and the lower incentive to screen and monitor credit risk under an OTD business model could decrease it. A bank knowing that it will sell credit risk after signing a loan contract will tend to put less effort into screening ex ante and into monitoring ex post which could lead to an inefficiently high level of credit risk in the economy as a whole. Moreover, banks may try to use CDS contracts for speculative purposes which they may find beneficial especially when pricing mechanisms in CDS markets do not function properly.

The purpose of our paper is to analyze the interplay of bank lending, credit risk transfer and regulatory requirements in order to derive conclusions regarding a bank's decision on granting risky loans. We focus on a risk-neutral bank and CDS contracts used primarily for hedging purposes. In our analysis we put considerable emphasis on modeling capital adequacy rules and their influence on a bank's lending and hedging behavior in a way that correctly reflects the Basel rules and allows for considering the effects of price distortions in CDS markets. More specifically we ask the following questions: How does capital adequacy regulation affect a bank's lending behavior? How does a bank react to increases in risk (without regulation or with regulation)? How does credit risk transfer with credit default swaps (CDS) affect bank lending conditional on pricing in the derivatives markets? Having seen credit risk transfer under heavy attack in the aftermath of the recent banking crisis, we also want to contribute to a realistic view on the pros and cons of this part of a bank's risk management. The ongoing discussion about CDS being extremely dangerous, in our opinion, needs to be brought back down to earth. Frictions in CDS markets that prevent the formation of correct CDS prices and create incentives to some market participants to abuse CDS contracts for speculative purposes should not conceal the potential value of CDS as instruments of a more sophisticated credit risk management.

Our analysis confirms that capital adequacy regulation lowers loan volume and increases the interest rate on loans. In addition we find that a bank reduces loan volume and increases interest on loans as a reaction to an increase in credit risk in the sense of a first-order stochastic dominance (FSD). A capital regulation sensitive to risk amplifies the bank's reaction to a risk increase. If, however, capital regulation is insensitive to risk, the bank's behavior following a risk increase is exactly the same as in the case without regulation.

Capital adequacy regulation also interacts with the bank's position in the CDS market. Without regulation a bank will not use credit risk transfer as long as the CDS market is unbiased, i.e., the derivative price is equal to the expected loss rate. The bank will sell credit risk to the maximum possible amount when the CDS contract is priced below the expected loss rate (and it will want to buy credit risk to the maximum possible amount in case of an upward distortion). This behavior may be interpreted as driven by a speculation motive: in a downward biased (upward biased) CDS market the bank speculates on loans to default (loans not to default) by extremely over-hedging (assuming additional) credit risk. Under capital regulation of the Basel II (and III) type a bank will have a stronger incentive to use credit risk transfer, if the CDS market is unbiased and the counterparty has a lower risk weight (better rating) than the lender. The amount of hedging chosen still depends on the price of CDS contracts: if the market is downward biased, unbiased or upward biased, the bank will find it optimal to over-hedge, fully hedge or under-hedge its total credit risk exposure, respectively. We observe, however, that capital adequacy regulation weakens a bank's motive to over-hedge or under-hedge its total credit risk exposure in biased CDS markets. That is, regulation weakens a bank's speculation motive. Furthermore, the hedging decision affects a bank's lending behavior contingent on the price of CDS contracts and the corresponding hedging strategy: if the CDS market is downward biased, unbiased or upward biased, the bank will find it optimal to increase lending, leave the volume of loans unchanged or reduce lending compared to an unregulated bank, respectively.

The plan of the paper is as follows: In the next section we briefly review the literature (II.). Section III. contains our basic model and an analysis of how a bank reacts to changes in risk both in a regime without and with capital adequacy regulation. We then introduce credit risk transfer and examine the influence of regulation on hedging and loan decisions (IV.). Section V summarizes and discusses our results.

II. Review of the Literature

In an article written in (pre-crisis) 2007 *Duffie* (2008) summarizes a large number of aspects concerning credit risk transfer and on the whole takes a positive view. Earlier on, *Instefjord* (2005) pointed already to the fact that bank risk can increase when credit risk is tradable. The effect that credit risk transfer induces banks to take on more risk can be dominant, in particular when competition in the banking industry is strong.

Wagner/Marsh (2006) find that banks have an increasing incentive to transfer credit risk off their balance sheets as opportunities for credit risk transfer (CRT) improve. As a consequence, they increase their risk-taking by expanding the volume of loans. This has, however, no effect on a bank's exposure to credit risk, since the additional risk is also transferred to the CRT market. In other words: banks fully hedge their credit risk exposure when there exist adequate opportunities for credit risk transfer. Similar full-hedge results can be found in work by Broll and various co-authors, e.g. *Broll* et al. (2004). As soon as no perfect hedge instrument is available, e.g. because of the existence of basis risk, the full-hedge propositions break down and an increase in loan volume coincides with an increase in risk. A dynamic analysis of the use of credit derivatives as a risk management device in provided is *Broll/Gilroy/Lukas* (2007).

The paper by *Wagner* (2007) argues that an increased liquidity of bank assets may increase banking instability and the externalities associated with bank failures. Higher asset liquidity, on the one hand, enables banks to reduce their exposure to risk and thereby leads to more stability. On the other hand, however, higher asset liquidity creates an incentive for banks to take on new risks, which may offset the initial risk-reducing effect.

In an early contribution *Santomero/Trester* (1998) analyze the effects of improved liquidity in bank loan markets (due to, e.g., securitization, credit derivatives etc.) on banks' supply of loans and risk-taking behavior in a model of asymmetric information. They find that decreasing costs of transmitting bank-specific information to the market causes a tradeoff between enhanced asset liquidity and increasing risk in banks because of more risky loans. More recent findings considering asymmetric information include *Duffee/Zhou* (2001) who use a model with moral hazard and adverse selection to analyze whether credit derivatives may be used to trade heretofore non-tradable credit risk exposures. They find that this is possible for those parts of credit risk exposures with a small degree of asymmetric information. However, using this opportunity to trade credit risk exposures may destroy other risk-sharing mechanisms and raise a bank's exposure to credit risk (for arguments see *Morrison* (2005)).

Turning to capital adequacy regulation we point to *VanHoose* (2007) who reviews the theoretical literature on bank behavior under capital requirements. He finds that this literature produces highly mixed predictions with regard to the effects of capital regulation on banks' risk-taking behavior.

Nicolo/Pelizzon (2008) investigate the optimal design of credit derivatives contracts in a setting of adverse selection where banks are subject to capital requirements. While this question is beyond the scope of our paper, their result that optimal credit derivatives contracts are largely dependent on bank regulation is also relevant for our analysis. In particular, the findings of Nicolo and Pelizzon suggest that asymmetric information may generate underpricing of credit derivatives products when capital requirements make the retention of risk costly for the bank which is especially true for credit default swaps (CDS). As we shall argue later, the results of *Nicolo/Pelizzon* (2008) support the assumption of downward-biased CDS prices which will play a role in the present paper.

As for the empirical side of credit risk management we first note that *Cebenoyan/Strahan* (2004) investigate empirically how active management of credit risk using loan sales affects capital structure, lending, profits, and risk of banks. They find that banks which are active in the loan sales market hold less capital and make more risky loans than other banks. They conclude that advances in credit risk management enhance credit availability rather than reduce risk in the banking system. *Goderis* et al. (2007) analyze whether the access to credit derivatives products markets affects banks' lending behavior. They find that banks which actively use credit derivatives increase their target loan volumes by around 50 % compared to banks that do not participate in credit derivatives markets. *Brewer III/Minton/Moser* (2000) empirically analyze the relation between bank participation in (interest-rate) derivatives contracting and bank lending. They find that banks which make use of interest-rate derivatives hold larger volumes of loans than banks which do not use derivatives.

Berndt/Gupta (2008) provide evidence that loan quality is lower for banks using the OTD business model because of adverse selection and moral hazard problems. *Purnanandam* (2010) shows this effect to be stronger for capital-constrained banks.

As for the use of credit derivatives, *Minton* et al. (2006), *Gibson* (2007), and *D'Arcy* et al. (2009) present information which is mostly based on data from the British Bankers' Association and the Bank for International Settlements. *ECB* (2009) addresses counterparty risk. *Mengle* (2007) provides data on counterparties and role of bank loans. *Meng/Ap Gwilym* (2007) analyze trading of credit default swaps based on single-name entities. They find that 81 % of underlyings are corporate debt and 12 % sovereign debt. Concerning the link between credit derivatives and capital requirements, see *ECB* (2009, 37–38).

A comprehensive discussion of the role of credit derivatives, in particular credit default swaps, in the recent banking crisis is presented in *Stulz* (2010). He addresses the linkages created between financial intermediaries by taking positions in markets for credit derivatives, an issue which is beyond the scope of the present paper.

The basics of the modeling approach used in our paper, the industrial economics approach to banking, can be found in *Freixas/Rochet* (2008).

Analyses of risk within this framework were performed e.g. by *Zarruk/Madura* (1992), *Wong* (1997), *Wahl/Broll* (2000), *Broll* et al. (2004), *Lin/Jou* (2005) and *Broll/Wong* (2010). We use the methodology of this literature and also follow its lead with respect to market structure, i.e. we consider a monopolistic bank. This enables us to include market power without having to deal with strategic interaction in a banking oligopoly. Our contribution consists in including capital regulation and credit risk transfer with CDS, and accounting for their interaction and joint impact on bank lending.

III. Model

1. Basic Setup

To model bank behavior we apply the industrial organization approach to banking (cf. *Freixas/Rochet* (2008), ch. 3), augmented by uncertainty of the credit risk type (cf. *Wong* (2007)). More specifically, we consider a one-period setting with a banking firm taking deposits D and giving loans L. The bank enjoys market power in both the deposit and loan market. D and L can be interpreted either as the total of homogeneous deposits and the total of homogenous loans or as aggregates representing well-diversified portfolios of deposits and loans, respectively.[1] The decisions on loans and deposits are made via the setting of loan and deposit rates r_L and r_D, respectively, at the beginning of the period.[2] The bank faces a loan demand function $L(r_L)$ with $L'(r_L) < 0$ and $L''(r_L) < 0$ and a deposit supply function $D(r_D)$ with $D'(r_D) > 0$ and $D''(r_D) < 0$.[3]

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[1] We do not deal with heterogeneous creditors and credit rationing. As a consequence there is no effect from total loan volume on the riskiness of the loan portfolio in our model.

[2] The deposit rate in our model represents in fact the expected interest rate paid to depositors. Credit risk causes bankruptcy risk of the bank which, in the absence of a perfect deposit insurance, needs to be assumed (at least partially) by depositors. In a seminal paper *Dermine* (1986) argues that in this situation a bank can no longer set loan and deposit rates independently. However, *Dermine* (1986, p. 107 f.) also shows that the decisions on loan rates and the expected deposit rate can be made independently which in turn allows for separation of a bank's decisions on the optimal volumes of deposits and loans.

[3] These concavity assumptions are made to simplify the exposition of our argument. They could be replaced by less restrictive conditions to ensure the concavity of the bank's objective function without changing the qualitative nature of our results.

Operational costs of financial intermediation are described by a cost function $C(D,L)$ with partial derivatives $C_D(\cdot) > 0$, $C_L(\cdot) > 0$, $C_{DD}(\cdot) > 0$, $C_{LL}(\cdot) > 0$ and $C_{DL}(\cdot) = C_{LD}(\cdot) = 0$. I.e., we assume the cost function to be convex in loans and deposits and do not consider any economies or diseconomies of scope.

Let $\bar{K}$ be the bank's equity capital. The balance sheet constraint can be written as $L + M = D + \bar{K}$, where M is the amount of excess ($M > 0$ when $L < D + \bar{K}$) or shortage ($M < 0$ when $L > D + \bar{K}$) in liabilities which can be lent or borrowed at a risk free interest rate $r > 0$. If we interpret the bank under consideration as one of a large number of local monopolists, this lending or borrowing would occur in a competitive interbank market for funds. Otherwise, r could be interpreted as an interest rate controlled by the central bank through its monetary policy.

The bank faces credit risk as a unique source of risk, i.e., we abstract from the interaction of different types of risk and focus on credit risk as the most important one in the traditional business of financial intermediation. For modeling credit risk we follow the lead of *Wong* (1997): Let the random variable $\tilde{\theta} \in [0,1]$ denote the share of the bank's loan portfolio which is non-performing at the end of the period in the sense that borrowers default both on payment of interest and on repayment of principal. Such non-performing loans have to be written off completely.[4] Let $F\left(\theta \middle| s\right) = \Pr\left(\tilde{\theta} \leq \theta \middle| s\right)$ be the cumulative distribution of credit risk conditional on the risk parameter s characterizing the riskiness of the bank's loan portfolio. We define an increase in risk using the concept of first-order stochastic dominance (FSD) as in *Wong* (1996) as

$$\frac{d}{ds} F(\theta | s) < 0 \quad \forall \theta \tag{1}$$

If s is higher, the cumulative distribution of θ is lower for all $\theta < 1$, i.e., the cumulative probability that credit risk takes on low values is lower. An increase in s increases the risk of the bank's loan portfolio. Note that we use FSD and not a mean preserving spread (cf. *Rothschild/Stiglitz* (1970)) to model higher risk. This is due to our perception that increases in the risk of a loan portfolio will typically not leave the mean unaffected.[5]

[4] Our approach could similarly be used to examine the case of borrowers only defaulting on interest payments or other forms of partial default.

[5] We are in line with the Basel approach to credit risk, which includes Loss Given Default and does not exclusively focus on Probability of Default.

Our bank is required to hold a minimum level of equity depending on the amount of risk-weighted loans. We specify this capital requirement condition as

$$\bar{K} \geq K\Big(\Lambda\big(L(r_L)\big|s\big)\Big) \quad \text{with} \quad K'(\cdot) \geq 0, \Lambda'\Big(L(r_L)\big|s\Big) \geq 0 \tag{2}$$

The functions K and Λ capture the regulatory rules. $\Lambda(\cdot)$ represents the risk-weighted loan volume, $K(\cdot)$ the regulatory equity required on the basis of $\Lambda(\cdot)$. The risk-weighted loan volume Λ is non-decreasing in the total volume of loans L, and a higher Λ requires more regulatory capital K. Reasonable regulation should, in addition, consider $\Lambda(\cdot)$ being an increasing function of s which is, for instance, the case for Basel-type regulation (see our appendix). Under Basel I and II, we have $\Lambda'(\cdot) > 0$ because the regulatory approaches for credit risk in the banking book assume that due to diversification there are no idiosyncratic components in credit risk. The remaining credit risk addressed by regulation is systematic, and therefore increasing loan volume L also increases Λ.[6] $\Lambda'(\cdot) = 0$ refers to the limiting case of a risk-weighting scheme such that an increase in loans does not lead to a higher risk-weighted loan volume. Under the Basel framework this could only occur in the Standard Approach and a risk increase limited to loans with a risk weight of zero. As we explain in the appendix, current Basel-type regulation also means that we have $\Lambda''(\cdot) = 0$, $\partial\Lambda'/\partial s > 0$ and $K''(\cdot) = 0$. The new Basel III accord developed in the follow-up to the banking crisis is also perfectly in line with (2).

Before conducting our formal analysis, it is necessary to take a look at the cost of capital r_K which we interpret as a required expected return on equity in the banking industry. That is, costs of capital in our model represent the amount per unit that needs to be paid on average to bank owners making them willing to provide the required equity capital.[7] The consensus in the literature is that the cost of capital has to be above the riskless rate of return in the market. Agency costs are probably the most important explanation for this statement. Such agency costs arise be-

[6] The existing regulatory framework assumes a positive asset correlation (*Basel Committee on Banking Supervision* (2005), 8–9). Under Basel III this assumed positive correlation can be expected to be even higher (*Basel Committee on Banking Supervision* (2010), 36–37).

[7] Our notion of cost of capital needs to be strictly distinguished from social cost of capital which measure whether requiring banks to hold equity is costly from a macroeconomic perspective. This latter aspect has recently been addressed by *Admati* et al. (2011).

cause of asymmetric information between the bank's management and the owners of its equity capital (see *Jensen/Meckling* (1976), and *Myers/Majluf* (1984), for details). In other words, due to agency costs $r < r_K$. Therefore, given the volume of loans and the level of the bank's credit portfolio risk, which does not depend on the loan volume by assumption, the bank is interested in employing the lowest level of equity possible. For that reason the regulatory constraint will be considered as binding in the sequel.[8] Moreover, asymmetric information may also be one reason why capital markets in the short run cannot adjust for events at banks and decisions of banks which are basically relevant for the pricing of equity capital. The cost of capital in the present model is, hence, considered as constant and exogenously given.

With this information the random profit of the bank can be written as

$$(3) \qquad \tilde{\Pi} = (1-\tilde{\theta})r_L L(r_L) - \tilde{\theta}L(r_L) + rM - r_D D(r_D) - r_K K\Big(\Lambda(L(r_L)|s)\Big) - C(D,L)$$

A tilde "~" denotes a stochastic variable. Substituting for M from the balance sheet constraint and collecting terms yields

$$(4) \qquad \begin{aligned} \tilde{\Pi} = {} & (r_L - r)L(r_L) - \tilde{\theta}(1+r_L)L(r_L) + (r - r_D)D(r_D) \\ & + (r - r_K)K\Big(\Lambda(L(r_L)|s)\Big) - C(D,L) \end{aligned}$$

Throughout the paper we consider a risk-neutral bank. We are aware of numerous reasons why actual bank behavior will probably be influenced by risk aversion or appear risk-averse. These reasons range from individual risk aversion of bank managers, convex taxation, and cost of financial distress to capital market imperfections (*Froot* et al. (1993); *Froot/Stein* (1998); for an application to banking see *Pausch/Welzel* (2002)). In our view the assumption of risk neutrality not only facilitates the analysis but also serves as a useful benchmark when looking at the interplay of risk management and capital regulation (*Pausch/Welzel*

[8] Given that the bank in our model may default at high realizations of credit risk, even an unregulated bank may prefer to hold a strictly positive amount of equity capital. *Dermine* (1986, p. 108) explains that equity capital can be used to reduce a bank's expected interest payments to depositors. Optimality then requires that the marginal cost of increasing the amount of equity capital just equates the marginal benefit from reducing expected interest payments to depositors. Regulatory capital constraints below a bank's own optimal amount of equity would, hence, not affect bank behavior. We therefore focus on the more interesting case of binding regulatory capital requirements in the sequel.

(2002) show that due to capital requirements a de facto risk-neutral bank behaves as if it were risk-averse).

2. *Bank Lending and Changes in Risk*

As mentioned before the overall aim of capital adequacy regulation under the Basel Accord is to improve the safety of the banking system. The existence of regulation should therefore reduce the bank's exposure to risk. As a consequence, even a risk-neutral bank, which sets deposits and loan rates to maximize expected profit, should be sensitive to risk, if there is capital adequacy regulation.

First-order necessary conditions of the bank's maximization problem are consequently

$$-\frac{D(r_D)}{D'(r_D)} - r_D + r - C_D(D,L) = 0 \tag{5}$$

$$(1-\bar{\theta})\left(\frac{L(r_L)}{L'(r_L)} + r_L\right) - (r+\bar{\theta}) - C_L(D,L) + (r - r_K)K'(\cdot)\Lambda'(\cdot) = 0 \tag{6}$$

where $\bar{\theta} = \mathrm{E}(\tilde{\theta})$.

Under our assumption on the cross-derivative of the cost function the decisions for deposit and loan rates can be separated. Therefore, equation (5) defines the optimal deposit rate and equation (6) defines the optimal loan rate. We observe that through $(r - r_K)K'(\cdot)\Lambda'(\cdot)$ the bank's loan business is affected by capital adequacy regulation which is not the case for its deposit business. $(r - r_K)K'(\cdot)\Lambda'(\cdot)$ is negative due to our assumptions on regulation and on the cost of equity capital. Therefore the loan rate unambiguously increases as a result of the introduction of the regulation.

We can thus state our first proposition:

Proposition 1: Capital adequacy regulation leads to an increase of the optimal loan rate and a decrease in the volume of loans.

Proof: To prove the proposition we adopt a similar proof from *Wahl/Broll* (2000). Using $(r - r_K)K'(\cdot)\Lambda'(\cdot) < 0$, (6) implies $(1-\bar{\theta})\left(L(r_L)/L'(r_L) + r_L\right) - (r+\bar{\theta}) - C_L(D,L(r_L)) > 0$ in the optimum. If there were no regulation, $(1-\bar{\theta})\left(L(r_L^u)/L'(r_L^u) + r_L^u\right) - (r+\bar{\theta}) - C_L(D,L(r_L^u)) = 0$ would characterize the bank's optimal behavior in the loan market with r_L^u denoting interest on loans in the absence of regulation. Comparing these two expressions, we get

$$(1-\bar{\theta})(r_L - r_L^u) > (1-\bar{\theta})\left(\frac{L(r_L^u)}{L'(r_L^u)} - \frac{L(r_L)}{L'(r_L)}\right) - \left(C_L(D, L(r_L^u)) - C_L(D, L(r_L))\right)$$

Assume, in contrast to Proposition 1, that the loan rate does not rise as a result of regulation ($r_L \leq r_L^u$). From our assumptions on loan demand $L(r_L)$ and operational costs $C(D,L)$ we know $L(r_L) \geq L(r_L^u)$, $L'(r_L) \geq L'(r_L^u)$ and $C_L(D, L(r_L)) \geq C_L(D, L(r_L^u))$. Keeping in mind $1-\bar{\theta} > 0$ and $L'(r_L), L'(r_L^u) < 0$, the above equation implies $r_L - r_L^u > 0$ which contradicts the assumption. □

The intuitive reason for this result is the following: Introducing capital adequacy regulation creates a link between both sides of the bank's balance sheet. A higher level of r_L lowers the volume of loans and thereby reduces the capital requirement and with it the cost of equity capital. Note that *Gehrig* (1996) also finds a negative impact of regulation on loan volume, but in his moral hazard framework it is the reduced incentive to monitor which drives this result. *Blum/Hellwig* (1995) provide yet another argument for a smaller loan volume under regulation. In their macroeconomic analysis capital adequacy regulation reinforces macroeconomic shocks by lowering equity of banks because of loan write-offs during a recession and thereby reducing loan volume. This procyclical effect of banking regulation received a lot of attention during the recent banking crisis. Our result emphasizes the direct impact of capital requirements on loan volumes which is perfectly in line with the regulatory objective of making bank failure less likely.

Note as a corollary of our proposition, that an increase in $K'(\cdot)$ which can be interpreted as stricter capital requirement will lead to a higher interest rate r_L and a lower volume of loans L. Moreover, because under any reasonable regulatory regime and under the Basel regime in particular (cf. the Appendix) the risk-weighted loan volume $\Lambda(\cdot)$ should grow when the level of portfolio credit risk $s$increases, due to $K'(\cdot) > 0$ a higher risk level immediately translates into a higher loan rate and a lower volume of loans. This effect of capital adequacy regulation reinforces the effect of a higher risk level on bank lending in the absence of regulation. Note that as a consequence of modeling an increase in credit risk by a FSD deterioration of the probability distribution of the share of non-performing loans a higher risk level implies a higher expected share of non-performing loans. Therefore even an unregulated risk neutral bank would, according to the arguments of the proof of Proposition 1, increase the optimal loan rate (i.e. reduce the optimal loan volume) when the level of portfolio credit risk grows.

Our insights can be summarized in the following proposition:

Proposition 2: A risk-neutral bank reduces its loan volume as a consequence of a first-order dominance increase in risk. Capital regulation reinforces this reduction in risk-taking.[9]

The interaction of risk and regulation restricts banks in their loan business and may create an incentive for credit risk transfer which we analyze in the next section.

IV. Credit Risk Transfer

Under the regulatory framework of Basel II (and Basel III) the use of credit default swaps (CDS) can affect the capital required for regulatory reasons. In particular, we include the hedging volume H in the function $\Lambda(\cdot)$ that determines the amount of risk-weighted assets to account for credit risk mitigation by CDS trading. The modified function

$$\Lambda(L(r_L), H \mid s) \tag{7}$$

is strictly positive for any level and combination of $L(r_L)$, H and s. With respect to the shape of this function the Basel requirements imply

$$\begin{aligned} \frac{\partial \Lambda(\cdot)}{\partial H} \begin{matrix} < \\ > \end{matrix} 0 \quad &\Leftrightarrow \quad \begin{matrix} (1+r_L)L > H \\ (1+r_L)L < H \end{matrix} \\ \frac{\partial \Lambda(\cdot)}{\partial L(r_L)} \begin{matrix} > \\ < \end{matrix} 0 \quad &\Leftrightarrow \quad \begin{matrix} (1+r_L)L > H \\ (1+r_L)L < H \end{matrix} \end{aligned} \tag{8}$$

Under the so-called substitution approach the volume of loans hedged by a CDS gets the risk weight of the counterparty.[10] Provided the coun-

[9] A detailed formal proof of the Proposition is available from the authors upon request.

[10] Since the substitution approach creates an incentive to transfer risk to unregulated non-banks and may thus have contributed to the recent banking crisis,

terparty's risk weight is below the original risk weight of the hedged loans, the bank can reduce the amount of risk weighted assets and, in turn, the amount of regulatory capital required, by hedging credit risk with CDS contracts. In the following we focus on this latter case and use it in the representation of the required regulatory capital in our model.[11] For a given loan volume, an increase (decrease) of the hedge volume H reduces (increases) the risk-weighted loan volume Λ, when the bank is under-hedged (over-hedged). Similarly, for a given hedge volume an increase in loan volume L increases (reduces) the risk-weighted loan volume Λ, when the bank is under-hedged (over-hedged). Moreover, at $(1+r_L)L = H$ the function $\Lambda(\cdot)$ is non-differentiable, but has a unique minimum as a consequence of the substitution approach.

Given that the counterparty's risk weight is less than the risk weight of a loan which is underlying a CDS contract, the substitution approach of the Basel frameworks implies a reduction of $\Lambda(\cdot)$ as the hedging volume increases for a given volume of loans. If a bank, however, buys more CDS contracts than required for completely hedging its credit risk exposure, the exceeding part of H will be treated according to the Basel market risk approach and thus will increase the amount of risk-weighted assets. A minimum level of $\Lambda(\cdot)$ will appear when hedging precisely covers the bank's exposure to credit risk. For a given amount of CDS contracts the amount of risk-weighted assets increases with a higher volume of loans as long as the bank's exposure to credit risk is not fully hedged. In case of over-hedging the total exposure to credit risk, an increase of the volume of loans decreases the amount of risk-weighted assets. When hedging activities precisely cover the bank's total exposure to credit risk, a marginal change of the loan volume does not affect the amount of risk-weighted assets.

Regarding the market for CDS, we assume that the bank can buy or sell any desired number of contracts. In particular, under such a contract the buyer of protection transfers credit risk $\tilde{\theta}$ to the seller. In exchange the seller of protection gets paid a certain premium which is denoted by p. We treat this premium as given, i.e., do not consider market power of the bank or its counterparty in the derivatives market.

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there is a debate whether the new Basel III framework should introduce modifications to this substitution (cf. *Deutsche Bundesbank* (2010), 50).

[11] Otherwise the bank would be in the rather implausible situation where capital adequacy regulation requires it to hold more capital for the hedged exposure to credit risk.

When making use of CDS, the bank's random profit can be rewritten as

$$\begin{aligned}\tilde{\Pi} = {} & (r_L - r)L(r_L) - \tilde{\theta}(1 + r_L)L(r_L) + (r - r_D)D(r_D) + (r - r_K)K(\cdot) \\ & + (\tilde{\theta} - p)H - C(D(r_L), L(r_L))\end{aligned} \tag{9}$$

where H denotes the amount of CDS contracts bought.

When the capital adequacy regulation did not account for a bank's activities in the CDS market, the optimal level of H is determined by the following first-order necessary condition:

$$\bar{\theta} - p = 0 \tag{10}$$

This condition supplements the first-order necessary conditions for the optimal deposit and loan rates which remain unchanged compared to the previous section.

Inspection of (10) reveals that when the CDS market is unbiased, i.e. $p = \bar{\theta}$, the bank is indifferent between any level of H and not participating in CDS trading at all. The reason for this is that participating in the CDS market does not affect the bank's expected profit it cares for under risk neutrality, when the market is unbiased. In this case $p = \bar{\theta}$ implies $H(\bar{\theta} - \bar{\theta}) = 0$. As a further implication of an unbiased CDS market note that variations in the level of credit risk, e.g. in the form of FSD analyzed above, are immediately reflected in the pricing of CDS contracts. As a result, a risk-neutral bank has no incentive to engage in CDS trading as long as there are no other mechanisms, for instance regulation, which make hedging a valuable activity.

When the exogenous price p of CDS contracts is lower than $\bar{\theta}$, i.e., the CDS market is biased in the downward direction, the first-order condition implies that it is optimal for the bank to buy the maximum available amount of CDS contracts. In this case CDS trading increases the bank's expected profit. The opposite holds when the price of the CDS contract is higher than $\bar{\theta}$. Optimality requires a negative value of H, i.e. the bank would prefer to become a seller of protection against credit risk since any positive amount of CDS contracts bought would reduce the bank's expected profit.

Our interpretation of this behavior is the following: Given our short-term perspective, price distortions in the CDS market generate speculation motives for banks. In a downward biased CDS market credit risk protection is so inexpensive that it is beneficial to the bank to speculate on loans to default. In this situation the actual value of the CDS payment in case of default is higher than the price to be paid for credit risk insurance. In contrast, in an upward biased CDS market credit risk protection is expensive. This makes it beneficial to a bank to speculate on loans not to default by assuming additional credit risk, i.e., becoming a protection seller. The actual value of credit risk protection now is lower than profits that can be earned from selling credit risk protection at the current market price. The previous analysis, moreover, shows that these speculation motives in a biased CDS market are maximal when the capital adequacy regulation does not account for credit risk transfer (or without any capital adequacy regulation).

Taking into account the modified specification of the function $\Lambda(\cdot)$, a risk-neutral bank maximizes the expected profit by setting deposit and loan rates as well as the hedging volume according to the following first-order conditions, respectively:

$$
\begin{aligned}
&-\frac{D(r_D)}{D'(r_D)} + (r - r_D) - C_D(D,L) = 0 \\
(11) \qquad &(1-\bar{\theta})\left(\frac{L(r_L)}{L'(r_L)} + r_L\right) - (r + \bar{\theta}) - C_L(D,L) + (r - r_K)K'(\cdot)\frac{\partial \Lambda(\cdot)}{\partial L(r_L)} = 0 \\
&(r - r_K)K'(\cdot)\frac{\partial \Lambda(\cdot)}{\partial H} + (\bar{\theta} - p) = 0
\end{aligned}
$$

The first-order condition for the optimal deposit rate is not affected by the current modifications of the model. As a result, the bank's optimal r_D remains the same as in the previous section.

For an analysis of the implications of CDS trading and its regulatory treatment on the optimal loan rate we first consider the bank's optimal hedging decision. We find that the bank chooses to under-hedge, fully hedge or over-hedge its total exposure to credit risk depending on the price of CDS contracts being higher, equal to or lower than the expected share of non-performing loans, respectively.

Consider first an unbiased CDS market. For $p = \bar{\theta}$ the first-order condition for the optimal level of H requires $\partial \Lambda(\cdot)/\partial H = 0$ due to $r - r_K < 0$ and $K'(\cdot) > 0$. Given (8) $\partial \Lambda(\cdot)/\partial H \neq 0$ as long as $H \neq (1 + r_L)L(r_L)$. Therefore the optimum in this case requires $H = (1 + r_L)L(r_L)$, i.e., a full hedge of the bank's exposure to credit risk. Moreover, the full hedge in the optimum implies that $\Lambda(\cdot)$ and therefore also $K(\cdot)$ is at its minimum. This minimum, however, is determined by the counterparty's risk weight which is exogenous to the bank. As a consequence, all regulation-related terms in the first-order condition for the optimal loan rate disappear. The remaining optimality condition is equivalent to the first-order condition for the optimal loan rate in the case without any regulation (section III). Hence, the availability of an unbiased CDS market implies the same optimal level of r_L as would be observed in the absence of any capital adequacy regulation. This result supports the attractiveness of the OTD business model when the CDS market is (nearly) unbiased, a perception many banks may have held before the recent banking crisis.

Note that considering an unbiased CDS market represents a kind of benchmark since it isolates the pure effect of capital regulation on bank behavior. When in the determination of regulatory capital CDS trading is considered to be risk reducing one observes an incentive for banks to engage in active risk management. Compared to a regulation that does not account for credit risk mitigation using CDS contracts banks' minimum required capital decreases. This, in turn, reduces banks' cost of capital and creates an income effect which is represented by the term

$$(r - r_K)K'(\cdot)\frac{\partial\Lambda(\cdot)}{\partial L(r_L)} < 0 \tag{12}$$

in the first-order necessary condition for the optimal loan rate. Moreover, under the Basel capital requirements the reduction of banks' cost of capital and hence the income effect reaches a maximum for the case of a full hedge of the bank's total exposure to credit risk.

When, in contrast, the CDS market is upward biased, i.e., $p > \bar{\theta}$, the previous full-hedge result is no longer optimal. Instead, the first-order condition for the optimal volume of H requires $\partial\Lambda(\cdot)/\partial H < 0$ which is the case only for $(1 + r_L)L(r_L) > H$ under the current assumptions. The bank now under-hedges, i.e. hedging activities cover just a part of the bank's total exposure to credit risk. This is the result of a tradeoff between the (high) price for credit risk mitigation in the CDS market and savings in capital costs due to the regulatory treatment of CDS contracts. The under-hedge result implies $\partial\Lambda(\cdot)/\partial L(r_L) > 0$ in the optimum. Compared to the situation with an unbiased CDS market, the first-order condition for the optimal loan rate now includes a strictly negative regulation-related term. As a result, derived from our previous reasoning, the regulated bank sets a higher loan rate compared to a non-regulated one.

In the case of a downward biased CDS market, i.e., $p < \bar{\theta}$, one observes from the first-order condition that the optimal hedging volume requires

$\partial\Lambda(\cdot)/\partial H > 0$ which is only met when $(1 + r_L)L(r_L) < H$. The bank over-hedges since both the effect of the low CDS price and the capital costs savings due to regulation aggravate each other. Regarding the optimal loan rate this implies $\partial\Lambda(\cdot)/\partial L(r_L) < 0$. Hence the regulation-related terms in the first-order condition for the optimal loan rate become positive and the optimal loan rate is lower than the one in the situation without any regulation. In other words: The bank expands the volume of loans compared to the non-regulated case.

From a capital market theory point of view one might argue that in particular in the latter situation of a downward biased CDS market there appears an oxymoron. Given that even without regulation (see previous results) there is an incentive for banks to demand CDS contracts and given that regulation aggravates this incentive, the price of CDS contracts may be expected to rise until the market is no longer biased.

However, as *Nicolo/Pelizzon* (2008) explain in their analysis of the optimal design of credit derivatives contracts in a setting of adverse selection and where banks are subject to capital requirements, their findings suggest that asymmetric information may generate underpricing of credit derivatives products when capital requirements make the retention of risk costly for the bank which is especially true for CDS contracts. Since this is exactly the situation which is considered in our paper, the results of *Nicolo/Pelizzon* (2008) support the idea that CDS markets might be downward biased.

In addition, there is some anecdotal evidence from the recent financial crisis: Before the onset of the crisis in 2007 the price of credit risk protection in general and CDS contracts in particular appeared to be correct. Ex post, however, the price of CDS contracts was found to be too low due to shortcomings in the pricing models. This initiated a large-scale re-pricing of credit risk protection. Against this background our model explains why banks took too large CDS positions.

We summarize the previous insights in our third proposition:

Proposition 3: A Basel-type capital adequacy regulation creates incentives for a risk-neutral bank to actively engage in hedging credit risk using CDS contracts even if the CDS price is unbiased. Depending on whether the CDS market is downward biased, unbiased or upward biased, the bank over-hedges, fully hedges or under-hedges its total exposure to credit risk.

The substitution approach embedded in current Basel capital regulation weakens a tendency towards corner solutions in hedging decision. It generates an income effect due to the hedging sensitivity of capital requirements. This income effect works against the effect arising from the potential biasedness of the CDS market. It prevents banks from taking extreme long or short positions in the CDS market. That is, capital adequacy regulation weakens a bank's speculation motives which may arise from price distortions in CDS markets as long as the current substitution approach for CDS hedging exists.

V. Discussion and Conclusion

In this paper we model a bank taking deposits and granting risky loans which is subject to capital adequacy regulation and may engage in credit risk transfer using credit default swaps (CDS). We take specific care to integrate Basel II (and III) regulations into the industrial organization approach to banking for our analysis of lending behavior and risk sensitivity of a risk-neutral bank. This enables us to examine the interaction of capital adequacy regulation and credit risk transfer with credit default swaps.

We find that a Basel-type capital adequacy regulation induces a risk-neutral bank to behave in a risk-sensitive way: Compared to an unregulated risk-neutral bank the volume of risky loans will decrease under regulation. Moreover, the reduction of the loan volume will be stronger as the riskiness of the loan portfolio increases.

We also find an interaction between the former effect of regulation and the bank's incentives to engage in credit risk transfer with CDS. When regulation accepts CDS as an instrument to mitigate credit risk, which is true for Basel II (and III), a risk-neutral bank will engage in CDS trading even if the CDS price is unbiased, i.e. the CDS price equals the expected loss rate of loans. In particular, due to the substitution approach in Basel II (and III) the risk-neutral bank finds it optimal to fully hedge its exposure to credit risk as long as the CDS price is unbiased. An upward or downward biased CDS price, however, implies an under-hedge or an over-hedge of the bank's credit risk exposure. In the latter situation of a biased CDS market the substitution approach in Basel II (and III) weakens a bank's motive to under hedge or over hedge its credit risk exposure.

These effects of the substitution approach in Basel II (and III) on bank behavior are in line with the intention of the Basel regulations to "strengthen the soundness and stability of banks": If capital adequacy regulation did not take into account the risk-reducing effect of CDS trading, it would stimulate a risk-neutral bank to take a more extreme position in a CDS market. This finding may be also interpreted in the sense that the current Basel capital regulation reduces a bank's motive to speculate on its loans to default or not to default when the CDS market is downward or upward biased, respectively. According to *Nicolo/Pelizzon* (2008) CDS markets could well be downward biased, especially in time of a crisis.

Note that our analysis covers both Basel II regulation and the current proposal for a new Basel III regulation. Basel III will increase the ratio of capital to risk-weighted assets, change the definition of equity, and deal with systemic risk. While the latter is no part of our research question, the former can easily be accounted for in our model.

When modeling increases in risk, we chose first-order stochastic dominance (FSD). We deliberately did not use a mean-preserving spread (MPS) since real-world risk increases in loan portfolios will typically not leave the mean loss rate unaffected (see *Pausch/Welzel* (2002), for an analysis of MPS-type risk increases). While FSD appears like a purely theoretical concept we would like to point out its relation to the concept of Value-at-Risk (VaR) used in banking. *Ogryczak/Ruszczyński* (2002) showed the equivalence of FSD and VaR, if one prospect has a lower VaR at all levels of risk tolerance than another.

In our view the analysis presented here can easily be re-interpreted to provide insights into a bank's optimal risk taking behavior with respect to other forms of credit risk transfer than CDS, e.g. securitizations, and other risky assets or its total asset portfolio, when there is capital adequacy regulation. We would again conclude that the interplay of capital regulation and risk transfer works in the right direction, making banks more stable against adverse shocks.

We should finally mention a few things we chose not to include in our model. Our specification of the bank's cost function uses a zero cross-derivative between the loans and deposits. Generalizing this assumption would amount to allowing for economies or diseconomies of scope between a bank's loan business and its deposit business. Economies would in some cases introduce an opposing force, but our results would be reversed only if these economies of scope were very strong.

If the bank we considered were risk-averse, there would be a genuine hedging motive. By focusing on a risk-neutral bank, we were able to isolate the effects of credit risk transfer and capital regulation and to work out how this makes a risk-neutral bank sensitive to risk.

Counterparty risk in the CDS market is no explicit part of our analysis. Note, however, that we have an implicit understanding of the role of counterparty risk: Since the sellers of protection against credit risk to a large extent are other financial institutions, we expect these institutions in many cases to have better ratings than the bank's borrowers. The Substitution Approach in capital regulation mentioned above then takes account of this change from a more risky borrower to a less risky seller of protection when credit risk transfer takes place.

The CDS we included in our model as hedging device provided a perfect hedge against the bank's credit risk. In reality there will hardly exist a derivative with a perfect (negative) correlation with the risk of a bank's loan portfolio. Remaining basis risk then leads to a reduction in the optimal hedge ratio compared to our analysis. Note also that credit derivatives in our model were only bought for hedging purposes. Including portfolio motives of a bank's buying (and selling) protection against credit risk would require a much more complicated model. Since banks are the dominant players on both sides of the CDS market, i.e. not only sell credit risk but also buy it, a duopoly model of banks holding more than one loan type and interaction at least in the CDS market would be needed. Such a model, which is beyond the scope of our present analysis, would focus on the CDS market, endogenizing CDS prices.

The recent banking crisis has increased the awareness of liquidity risk on behalf of bankers and researchers. Future research with the framework we used here might include liquidity risk via an uncertain interest rate in the interbank market.

Appendix

In this appendix we briefly outline how capital requirements for credit risk are calculated under Basel II (and also the proposal for Basel III), showing that our model captures the essential features of this regulatory framework.

The Basel frameworks provide several approaches – the Standardized Approach and the Internal Ratings Based (IRB) Approach – to determine capital requirements for credit risk. We, therefore, start with a closer look at the IRB Approach before we consider the Standardized Approach. For this purpose we build on an explanatory note of the *Basel Committee on Banking Supervision* (2005) and on a supporting document to the Basel II accord by the *Basel Committee on Banking Supervision* (2001).

Under the IRB Approach of Basel II (and III) a bank calculates the level of Minimum Required Capital (MRC) by multiplying Risk Weighted Assets (RWA) and a constant Capital Ratio (CR) which is 8 % times a scaling factor:

$$MRC = RWA \cdot \gamma \tag{A1}$$

Risk Weighted Assets (RWA) are derived by multiplying the Exposure At Default (EAD) with a Risk Weight (RW):

$$RWA = EAD \cdot RW \tag{A2}$$

The Risk Weight (RW), in turn, is a function of the Loss Given Default (LGD), Probability of Default (PD), and the assets' maturity:

$$RW = RW(LGD, PD, M) = CF \cdot LGD \cdot \Phi(PD) \cdot \Psi(M) \tag{A3}$$

where (CF) represents a constant factor, $\Phi(\cdot)$ is a function that determines the "effective PD" by correcting the initial PD for the correlation of assets in a bank's portfolio. In addition, $\Psi(\cdot)$ is a function of the "effective maturity" of the assets.

Since we consider a one-period setting, we can abstract from the maturity of assets. $\Psi(\cdot)$ is therefore irrelevant. The Exposure At Default (EAD) corresponds to the total volume of loans $L(r_L)$ in our model. The Basel framework assumes that EAD is independent of PD and LGD which is also an implicit assumption of our model.

In the Basel frameworks the PD needs to be determined for a bank's assets. In our model the PD is implicitly given by the probability distribution function of the share $\tilde{\theta}$ of non-performing loans. The PD in the model corresponds to the probability of default of the bank's total loan portfolio and is affected by the risk-shifting parameter s.

The Loss Given Default (LGD) in the Basel framework should be understood as the expected value of a random variable that determines the expected share of an asset that needs to be written off in the case of default. In the model the LGD, therefore, corresponds to $\bar{\theta}$. In the Basel frameworks the LGD is treated as a constant parameter that is either given by asset class (Foundation IRB Approach) or estimated by banks themselves (Advanced IRB Approach).

Note that in the model of the present paper the PD as well as the LGD may be affected by the risk-shifting parameter s. Increasing level of risk, i.e., when s grows, in our model the cumulative distribution function of non-performing loans deteriorates in the sense of first-order stochastic dominance. This implies an increase of the PD and the LGD of the bank's total loan portfolio in our setting:

$$\frac{dPD}{ds} > 0 \quad \text{and} \quad \frac{d\bar{\theta}}{ds} > 0. \tag{A4}$$

Given these interpretations, we can conclude that RWAs are derived from the function $\Lambda(\cdot)$ in our model which may be rewritten as

$$\Lambda(L(r_L) \mid s) = L(r_L)\Phi(PD)\bar{\theta}\ . \tag{A5}$$

for the case of the Basel framework.

Regarding $\Lambda(\cdot)$ we then derive

$$\begin{aligned} &\frac{d\Lambda(\cdot)}{dL(r_L)} = \Lambda'(\cdot) = \Phi(PD)\bar{\theta} > 0, \quad \frac{d^2\Lambda(\cdot)}{dL(r_L)^2} = 0, \\ &\frac{d\Lambda'(\cdot)}{ds} = \frac{d\Phi(PD)}{dPD}\frac{dPD}{ds}\bar{\theta} + \Phi(PD)\frac{d\bar{\theta}}{ds} > 0 \end{aligned} \tag{A6}$$

and

$$\frac{\partial\Lambda(\cdot)}{\partial\Phi(\cdot)} = L(r_L) > 0, \quad \frac{\partial^2\Lambda(\cdot)}{\partial\Phi(\cdot)^2} = 0. \tag{A7}$$

Moreover, the MRC is determined by the function $K(\cdot)$ in our model which can be written more explicitly after applying the Basel definitions as

$$MRC = K(\Lambda(\cdot)) = \Lambda(L(r_L) \mid s) \cdot \gamma \tag{A8}$$

with $K'(\cdot) = \gamma > 0$ and $K''(\cdot) = 0$.

Under the Standardized Approach for credit risk of Basel II (and III) risk weights (in the following denoted $\mathrm{RW}_{\mathrm{SA}}$) are predefined by asset class. A loan is then allocated to a certain asset class based on an external rating and on the borrower type. Regarding our model this procedure rules out a direct effect of the risk-shifting parameter s on the total volume of risk weighted loans via FSD. However, given a certain asset class risk weights vary depending on the external rating of an asset. As a result, in case of a rating downgrade the risk weight of a certain asset may increase. In our setting this implies for the Standardized Approach:

$$\begin{aligned} &\Lambda(L(r_L) \mid s) = L(r_L)RW_{SA} \\ &\frac{d\Lambda(\cdot)}{dL(r_L)} = \Lambda'(\cdot) = RW_{SA} \geq 0, \quad \frac{d^2\Lambda(\cdot)}{dL(r_L)^2} = 0, \\ &\frac{d\Lambda'(\cdot)}{ds} = \frac{dRW_{SA}}{ds} \geq 0 \end{aligned} \tag{A9}$$

The minimum capital requirement is then determined by multiplying risk weighted assets by a constant factor. Therefore we observe $K'(\cdot) > 0$ and $K''(\cdot) = 0$ also under the Standardized Approach of Basel II (and III).

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