Theories of Bank Solvency Regulation

Eetu Marjasvaara

School of Business

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Thesis supervisor:

Asst. Prof. Miri Stryjan

Aalto University
School of Business

AALTO UNIVERSITY
SCHOOL OF BUSINESS

ABSTRACT OF THE
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Author: Eetu Marjasvaara

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This thesis is a literature review of the main theories of bank solvency regulation, means of exogenously controlling banks' riskiness. The thesis starts with a review of the main market failures that necessitate the regulation of banks. Then I proceed to cover the portfolio approach, a seminal strand of solvency regulation literature considering the use of capital regulation. Following this, I explore the shortcomings of the portfolio approach by considering bank incentives in different frameworks of principal-agent problems and monopolistic competition, and finally, by considering interactions between the banks' management and owners. This is followed by a discussion on how the literature's suggestions on optimal solvency regulation loosely correspond to actual solvency regulation under the Basel Accords.

Keywords: Bank regulation, Financial stability

Espoo, 27.12.2022 Eetu Marjasvaara

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1 Introduction

Controlling the riskiness of banks is a key objective for regulatory authorities. This has been highlighted by the recent introductions of new regulatory schemes (Basel Committee on Banking Supervision (2017)). The methods of controlling the riskiness of banks are called solvency regulation and mostly consist of differing forms of capital regulation - means of controlling bank risk through capital requirements. Despite the prevalence of capital requirements, the means of solvency regulation also include more nuanced proposals, such as setting ceilings on the deposit rates banks are allowed to offer. At the core of the current global solvency regulation framework are the three Basel Accords of 1988, 2004, and 2011. These accords consist of regulatory recommendations by the Basel Committee on Banking Supervision (BCBS) that member states have agreed to incorporate into their legislation. The Basel Accord framework has been accredited with successfully coordinating a global convergence of banking regulation into a system of improved capital standards (Santos (2001)).

However, the Basel framework has also received criticism for not properly addressing many relevant problems [1]. The global financial crisis of 2007-2009 provides a stark example of such a situation where solvency regulation failed to prevent excessive risk taking in the banking system. In the years leading up to the financial crisis, banks extended inefficiently large amounts of lending to the public through subprime mortgages, which fuelled by loose regulation of securitization and mortgage-backed securities (Dewatripont and Tirole (2010)). When this subprime mortgage bubble burst, it led to bank failures in the United States which plunged the United States and other economies into recession and made financial markets dysfunctional (Reserve Bank of Australia (2022)).

The financial crisis highlighted many shortcomings of the then prevailing Basel II solvency regulation framework, including opaque modelling of risks and insufficient capital requirements. Subsequently, it prompted the introduction of a large regulatory reform as the third Basel accord was published in 2011. It is due to to be fully operational at the end of the phase-in period in 2027 and addresses many of the shortcomings of Basel II (Basel Committee on Banking Supervision (2017)).

As bank solvency regulation handles topics with broad ramifications for the economy and has many ongoing developments, it has attracted a large and far-reaching literature [2]. In such a large body of literature, it is key to understand the seminal literature and grasp the most important channels through which solvency regulation affects banks'

[1] For points of criticism on the Basel framework see Moosa (2010) on Basel II and Allen et al. (2012) on Basel III.

[2] See Santos (2001) and VanHoose (2007) for surveys on the literature on bank solvency regulation.

decisions. By formally defining and modelling key phenomena we can gain intuition and rigorous understanding of the building blocks of more complex regulatory frameworks, such as those currently in place under Basel III. In light of this, the contribution of this thesis is to cover and analyze the main theories of bank solvency regulation. Through conducting a literature review, I contrast the assumptions of different theories and their implications, analyzing the underlying forces driving solvency regulation and banks' reactions to it.

Models on bank solvency regulation point to a mixed set of implications that depend largely on the setting that researchers choose to emphasize. The three main approaches that I find the seminal literature being divided into are the portfolio approach, the incentive approach, and the incomplete-contract approach. As there are many different theories of bank solvency regulation that convey different policies, the main challenge of this thesis is to coherently present and analyze multiple models with differing assumptions and conclusions. I handle this by first covering the standard portfolio models used in the field, after which I move on to models in the incentive and agency problem approach that relax various assumptions embedded in the portfolio models.

In seminal portfolio approach banks are treated as managers of a portfolio of assets. As such, it views banks' portfolio choices through a slightly modified Markowitz mean-variance optimization model or alternatively the capital asset model (CAPM) [3]. This portfolio literature is a standard approach in the literature as it provides a simple framework for analyzing capital regulation as a way of decreasing the risk that banks have in their asset portfolios. Methods of capital regulation in the portfolio approach include for example leverage ratio requirements (Koehn and Santomero (1980)) and risk-weighted minimum capital requirements (Kim and Santomero (1988)).

Due to the simplicity of the portfolio approach, it is nonetheless left susceptible to criticism. Addressing many of the shortcomings of the portfolio literature, the incentive approach considers the incentives that banks face under solvency regulation. The literature on the incentive approach is a large and heterogeneous as it considers many possible mechanisms of bank solvency regulation. These include for example breachable capital requirements (Milne (2002)) information disclosure between banks and regulators (Blum (2008)) and moral hazard under monopolistic competition (Hellmann et al. (2000)). The seminal portfolio literature also fails to consider any interactions between bank management and ownership, which are analyzed in the agency problem approach. M. Dewatripont and J. Tirole (1993) consider differences in incentives between bank

[3] For references on these well-known optimization and pricing models see Markowitz (1952) for the mean-variance portfolio optimization model and Sharpe (1964) for the CAPM.

management and the ownership, building on the foundations of M. Dewatripont and J. Tirole (1994).

I find that in terms of the recommendations for the optimal methods of solvency regulation, the literature is very context specific. This is due to the regulatory suggestions often being intertwined with the particular mechanisms that researchers choose to emphasize. The portfolio approach, which considers purely monetary factors relating to risk and return on assets, finds that optimal regulation consists of only capital regulation. Literature on the incentive approach tends to conclude that optimal regulation consists of capital regulation and some other form of solvency regulation relating to the mechanism under study. When attention is shifted towards a totally different set of problems within the banking firms' structure in the agency problem approach, optimal regulation consists of threatening managers with harsher control of the bank - a totally different proposition compared to the different approaches

The thesis proceeds as follows. In a section on background, I cover the main market failures that are used as justification for the regulation of banks. After covering the necessary background, I start by going over a large strand of literature in bank solvency theory, the portfolio approach. I then move on to the incentive approach, which relaxes many of the assumptions the portfolio approach makes. I then shift attention to the structure of the banking firm and cover the agency problem approach. Finally, in the discussion section I contrast the conclusions of the theory on optimal solvency regulation to the current Basel framework, after which I conclude the thesis and point the reader towards further reading.

2 Background

The banking system is characterised by many market failures, such as problems with of moral hazard (Keeley (1990)) and asymmetric information (Blum (2008)). Subsequently, there exist many different justifications for the regulation of banks. These justifications are necessary for understanding the literature on banking regulation as all models either explicitly model or implicitly assume some form of these market failures. These justifications are further explored in this section.

As VanHoose (2007) presents, the risk shifting incentives that deposit insurance schemes create by inducing less risk aversion in banks' decision is a recurring theme in much of the literature on bank solvency regulation. To understand this insured deposits argument, it is key to discuss the underpinnings of the existence of banks.

In banking theory, the existence of banks is often justified as them being the provision of monitoring and liquidity services. More consequentially for the theory of solvency regulation than the monitoring argument [4], banks provide depositors with liquidity insurance as they offer deposits with positive rates of return, while also allowing depositors to withdraw funds at any moment Diamond and Dybvig (1983)). By issuing these demand deposits, banks act as risk sharing platforms that can better absorb the risks posed by liquidity shocks to households than households themselves. However, this leaves banks vulnerable to runs on deposits because the households' need for liquidity is not publicly observable and thus a Nash equilibrium where all households want to withdraw deposits exists. In this bank run equilibrium, banks are unable to pay all depositors back in full due to the maturity mismatch between their short-term assets and long-term liabilities.

Through the liquidity provisions depicted by Diamond and Dybvig, banks are by nature left exposed to bank runs. To insulate bank deposits from runs and thus protect depositors, deposit insurance schemes have been created by governments such as the US Federal Deposit Insurance Corporation (FDIC) and the EU-wide European Deposit Insurance scheme (EDIS), due to replace the current national deposit guarantee schemes in the EU (European Comission (2015)). These schemes do not however come without social cost. If banks have their customers' deposits insured by a deposit insurance scheme, they have incentives to take excessive risks. This is because through the insured deposits the banks' downside loss is limited, and the depositors have very limited to no capital at risk and thus their monitoring incentives are fully discarded (Kareken and Wallace (1978)).

Keeley (1990) presents evidence that competition between banks can induce excessive risk taking by banks. This is due to the present value of a banks' future profits, also called the banks charter value, decreasing under increased competition, banks have less to lose and thus can take excessive risks by gambling on resurrection - choosing a riskier than optimal assets, where ultimately the taxpayers funding the deposit insurance scheme are left with the losses if the gamble fails. Against this backdrop, competition in banking leads to a market failure characterized by moral hazard, that necessitates solvency regulation.

When attention is shifted to the structure of the banking firm, the interactions between bank management and ownership become the source of the market failure. M. Dewatripont and J. Tirole (1994) argue that equity holders side with the bank management on taking riskier decisions than would be socially optimal. The debt owners of the bank (the depositors) would be willing to tolerate less risk than equity holders,

[4] See Diamond (1984) for an explanation on banks as the provision of monitoring.

but them exercising their rights to control the bank can be infeasible due to the small and dispersed nature of depositors.

3 The Portfolio Management Approach

The portfolio approach is a large and defining strand of literature on bank solvency regulation. The main feature of the portfolio approach is that banks behave as mean-variance optimizers when they choose the composition of assets in their portfolios. When banks exhibit such behaviour, altering a bank's portfolio composition and riskiness through capital requirements becomes the main role of solvency regulation. With this tool of capital requirements regulators enforce solvency regulation by forcing banks to have sufficient amounts of "safe" regulatory capital, aiming to make banks less risky. The portfolio approach creates a role for bank solvency regulation through implicitly assuming a deposit insurance scheme that distorts banks' incentives and leads to them choosing riskier portfolios of assets Kim and Santomero (1988).

Due to many real-life imperfections in financial markets, the portfolio literature presented in this thesis assumes that markets are not Arrow-Debreu complete (Arrow and Debreu 1954). Accepting the Arrow-Debreu complete markets hypothesis would have the ramification that there would be no transaction costs and all assets would have prices in all states of the world, a clearly incoherent assumption as the banking system is characterized by many imperfections such as asymmetric information. Rochet (1992) contends that the complete market assumption would be the only feasible way of justifying banks' value maximizing behaviour. As a proxy for incomplete markets, banks are utility maximizing instead of value maximizing in the portfolio approach.

In the seminal literature of the portfolio approach Kahane (1977) and Koehn and Santomero (1980) consider the effects of a a portfolio leverage ratio requirement - a simple minimum capital requirement - in a mean-variance framework. They show that imposing a leverage ratio requirement can counterintuitively lead to banks increasing the riskiness of their portfolios. Kim and Santomero (1988) further build on this model by exploring risk-weighted minimum capital requirements as a way of preventing these adverse asset allocations under a leverage ratio requirement. Rochet (1992) provides an alternative interpretation of the previous portfolio models in the capital asset pricing model (CAPM) and shows that a more realistic limited liability bank can take even riskier portfolios as a response to capital regulation. The next sections further explore the models in the portfolio approach.

3.1 Leverage Ratio Requirements

This section explores the seminal model presented by Koehn and Santomero (1980) and Kim and Santomero (1988). It is a model of fully liable banks that face perfect competition in all their respective markets. The banks, considering only the mean-variance characteristics of their portfolios, maximize the expected utility derived from second period capital with given portfolio risk and capital requirements. This utility maximizing behavior is due to the literature discarding the complete market hypothesis as argued before. The banks are also assumed unable to purchase a risk-free asset, but the payout r_0 to depositors is deterministic.

The capital requirements are enforced through an ex-ante binding leverage ratio constraint c. In this leverage ratio constraint, all banks must have regulatory capital K as a fraction of total assets A equal to at least c so that $\frac{K}{A} \geq c$. This regulatory capital in real world instances includes for example government liabilities and other assets deemed sufficiently safe and liquid. In this setup, a portfolio optimizing bank maximizes expected return for given variance, or equivalently minimizes portfolio variance for given expected return, and thus faces the following optimization problem:

$$\min_{\boldsymbol{x}} \langle \boldsymbol{x}, \boldsymbol{V}\boldsymbol{x} \rangle - \lambda_0 \bar{r} \tag{1}$$

Subject to

$$x_0 \geq 1 - \frac{1}{c} \tag{2}$$

$$\sum_{i=0}^{n} x_t = 1 \tag{3}$$

Where $\boldsymbol{x} = [x_0, \dots, x_n]^T$ is the vector of the proportions x_i of asset i from the bank's total portfolio value. $\boldsymbol{r} = [r_0, \dots, r_n]^T$ is the vector of expected asset returns. Asset $i = 0$ denotes the negative deposit asset of the bank and thus $r_0 \leq 0$ and $x_0 \leq 0$. $\boldsymbol{V}$ denotes the covariance matrix of asset returns, through which the portfolio variance, also called portfolio risk, is written as $\sigma^2 = \langle \boldsymbol{x}, \boldsymbol{V}\boldsymbol{x} \rangle$. E denotes the total expected rate of return on the portfolio $E = \langle \boldsymbol{x}, \boldsymbol{r} \rangle$. Crucially for the analysis, Equation (2) illustrates the capital regulation $\frac{K}{A} \geq c$. It is the bank's leverage ratio constraint, which sets a limit to how much the bank is able to leverage its asset portfolio through deposits. For example, if $c = 0.1$ the bank can then leverage its asset portfolio 9-fold through deposits as $x_0 = -9$.

Solving the above optimization problem defines an efficient frontier EF in (E, σ)

space, which is in the absence of capital regulation the global efficient frontier GF. This is illustrated in Figure 1. At optimum the marginal rate of substitution between portfolio risk and return equals the shadow price of portfolio risk, the marginal rate of transformation along the efficient frontier $MRS_{\sigma^2,\bar{r}} = \lambda_0$. Koehn and Santomero show that, given each banks utility function, each bank is guaranteed an unique optimal portfolio on the efficient frontier EF. The composition of this portfolio $x(\Gamma)^*$ depends on a banks risk aversion parameter Γ, the bank's Arrow-Pratt relative risk aversion coefficient. The lower the risk aversion coefficient Γ, the more risk the bank is willing to have in its optimal portfolio.

Were banks not to reshuffle portfolios due to changes in the leverage ratio requirement c, Koehn and Santomero argue that increasing and thus tightening the leverage ratio requirement c, all else equal, decreases the expected returns and expected risk of bank portfolios on the efficient portfolio. Subsequently, this results in a desirable outcome from the point of view of the regulators, where the entire efficient frontier has less expected profit and risk for all bank portfolios. However, the key problem is that banks respond to the tightening of the leveraging constraint through the optimization problem, reshuffling their portfolios along their new efficient frontier, and thus all else does not stay equal when the capital requirements are changed.

For further insight, Kim and Santomero analyze the probability of bank failure under differing portfolio compositions. They contend that for a prudential regulatory authority interested in making the banking system more safe and sound, an apparent goal would be to assign an upper bound for the probability of a bank failing. Now assume that expected returns on bank assets r_i, except for the deterministic cost on deposits r_0, are normally distributed (note that the normality assumption here is not necessary, as we can bound the probability of failure using Chebyshev's inequality as Koehn and Santomero do). The event where bank insolvency occurs is when the bank has its equity capital fully diminished $E < -1$. It is well known that as the individual returns on assets are normally distributed, so is any linear combination of these returns, including the expected return of the portfolio E. From this normality assumption we can infer the following through standardizing the distribution of the portfolio expected return E.

$$\mathbb{P}[E < -1] = \mathbb{P}[0 < \frac{E+1}{\sigma}]$$

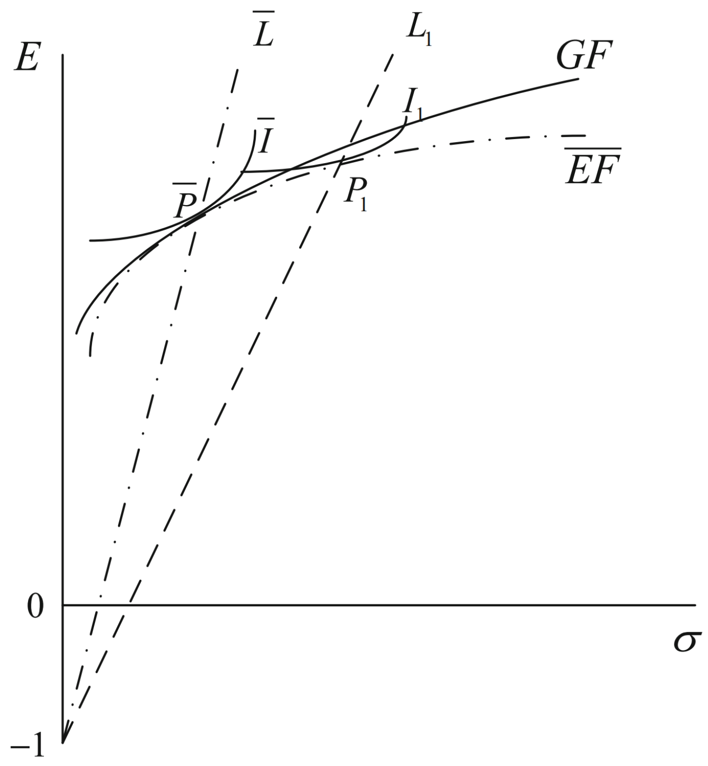
$$E = -\sigma \cdot \Phi^{-1}(\mathbb{P}[E < -1]) - 1 \tag{4}$$

By setting the probability of insolvency equal to a constant α in Equation (4), we define a line L in (E, σ)-space, along which the probability of insolvency is constant and a larger slope corresponds to a lower risk of insolvency.

$$L: \quad E = -\sigma \cdot \Phi^{-1}(\alpha) - 1 \tag{5}$$

Now consider an unregulated banking system, where banks choose the composition of risk and return along the global frontier GF in figure 1. The regulatory authority wants to decrease the risk in banks' portfolios, and so aims to set an upper bound α on the probability of bank insolvency, corresponding to the line $\bar{L}$ in Figure 1. The regulator tries to implement this by setting a corresponding leverage ratio requirement $c_1 > 0$, hoping that banks would choose a portfolio to the left of $\bar{P}$ and not choose the riskier points to the left of $\bar{P}$ on GF. In fact, this regulation does render these unwanted portfolio compositions of GF infeasible and were banks not to adjust the compositions of their portfolios in response to this constraint, this would indeed reduce the overall riskiness and bound the probability of insolvency by the chosen α. This demonstrates the portfolio risk decreasing direct volume effect of more constrained leveraging through deposits.

Figure 1: Efficient frontiers and insolvency probabilities. David VanHoose (2017). "Capital Regulation, Bank Behavior, and Market Structure". In: *The Industrial Organization of Banking.* 2nd ed. Springer, pp. 175–206



However, while the unwanted region of GF is rendered infeasible by this capital regulation, the regulator fails to account for the adverse structure effect of possibly taking on more risk through portfolio reshuffling as a response to more constrained leveraging. When banks reshuffle their portfolios as a response to the capital regulation, they can feasibly increase risk beyond that of portfolio P along the new efficient frontier EF, which corresponds to the optimization problem with leverage ratio of c_1. As previously stated, the risk aversion of the bank determines the amount of risk they are willing to have in their reshuffled portfolio, which is illustrated in Figure 1 by the two indifference curves of banks, $\bar{I}$ and I_1. As I_1 has more curvature and thus smaller risk aversion Γ, the corresponding bank chooses more risk in its reshuffled portfolio than the bank with $\bar{I}$.

The Kim and Santomero show that there exists an explicit value of the risk aversion coefficient $\hat{\Gamma}$ such that for all banks with a risk aversion coefficient $\Gamma < \hat{\Gamma}$ the portfolio adjustment response to tightening leverage constraint will be to shift towards a riskier portfolio associated with a higher probability of insolvency. For these banks, the direct volume effect of more constrained leveraging through deposits is dominated by the adverse structure effect of taking on more portfolio risk. Through this mechanism, we arrive at a fundamental conclusion of the model. When a regulator implements solvency regulation through tightening the leverage ratio requirement, the change in total riskiness of the banks' portfolios depends on the distribution of risk aversion in the banking system. For a banking system with low risk aversions, it is possible that tightening the leverage ratio requirement results in the overall insolvency risk actually increasing, undermining the regulatory goal of decreasing insolvency risk.

3.2 Risk-Weighted Minimum Capital Requirements

Due to the possibly adverse effects of implementing capital regulation through a leverage ratio, Kim and Santomero (1988) consider implementing capital regulation through a risk-weighted minimum capital requirement. This capital requirement assigns risk-weights w_i for each asset i in the calculation of the minimum capital requirement, and contrary to the leverage ratio, fully neglects any consideration on the amount of deposits. Denote $\tilde{\boldsymbol{x}} = [x_1, \ldots, x_n]^T$ the vector of assets, excluding the negative deposit asset x_0. Under the risk-weighted minimum capital requirement, banks must have regulatory capital K as a fraction of total risk-weighted assets (RWA) equal to at least c so that $\frac{K}{\langle \tilde{\boldsymbol{x}}, \boldsymbol{w} \rangle} \geq c$. Such a risk-weighted minimum capital requirement can also be written in normalized form with an arbitrary positive constant C as

$$\langle \tilde{\boldsymbol{x}}, \boldsymbol{w} \rangle < C \tag{6}$$

As was the goal in the previous subsection, regulators want to set a maximum risk of insolvency α for all banks. With the leverage ratio requirement regulators were unable to restrict the efficient frontiers of banks to only such points that have insolvency risk equal or lower than α, which left the effects on total riskiness ambiguous. Kim and Santomero show that with a risk-weighted minimum capital requirement, the banks can indeed be forced to choose portfolios on a efficient frontier frontier that has insolvency risk bounded by α. To achieve this, the regulator must set for each asset i the risk weights w_i so that the return on one unit of x_i is bounded above by $E_{\bar{P}}$, the expected total portfolio return at $\bar{P}$ in Figure 1, but exceed the deposit-financing costs. Under such weights, it is trivial that no return of a portfolio consisting of the assets can either exceed $E_{\bar{P}}$. Kim and Santomero explicitly solve for such optimal weights $\boldsymbol{w}^*$ and show that by applying these optimal risk weights in the minimum capital requirement, all banks have their insolvency probability bounded by the chosen α, which adheres to the goal of the regulator in creating a safer banking system by decreasing the risk of insolvency.

Rochet (1992) criticizes Koehn and Santomero (1980) and Kim and Santomero (1988) for treating banks as having full liability over their liabilities. This assumption creates an inconsistency in the model, as in real world instances banks have limited liability over their liabilities. Rochet provides a similar analysis to the previous model, but with this limited liability clause included in the banks' objective functions. This analysis shows that discarding the limited liability assumption has an important implication for the usage of the risk-weighted minimum capital requirements. Under limited liability, the adverse effects related to minimum capital requirements become even larger and thus not even correctly set risk-weighted minimum capital requirements are enough in all cases to restrict banks from increasing portfolio risk as a response to the capital requirements. This is because under limited limited liability banks can become risk loving.

3.3 Capital Asset Pricing Model

Rochet (1992) and Freixas and Rochet (2008) provide a powerful general equilibrium framework for the interpretation of the model of full liability banks by Koehn and Santomero (1980) and Kim and Santomero (1988) in the capital asset pricing model (CAPM). This is due to the addition of a risk-free asset with return r_f that the bank is able to purchase, which has the well-known implication that all banks choose colinear portfolios that are linear combinations of the risk-free asset and an efficient market portfolio of assets $\boldsymbol{x}_M$ with return r_M and variance σ_M^2. This linear combination of the risk-free asset and the market fund, which forms the efficient frontier in (E, σ)-space, is commonly referred to as the capital market line. This CAPM allocation of banks' assets along the capital market line is

$$\boldsymbol{x}^* = \lambda \boldsymbol{V}^{-1}(\boldsymbol{r} - r_f), \quad \lambda > 0 \tag{7}$$

Which communicates that, under the CAPM, all banks choose colinear portfolios with respect to their risk aversity characteristics λ. When a risk-weighted minimum capital requirement with weights $\boldsymbol{w}$ is imposed, the banks' portfolio solution becomes

$$\boldsymbol{x} = \lambda \boldsymbol{V}^{-1}(\boldsymbol{r} - r_f) + \boldsymbol{V}^{-1}\langle \boldsymbol{\gamma}, \boldsymbol{w} \rangle, \lambda > 0 \tag{8}$$

Where, for our purposes, $\boldsymbol{\gamma}$ denotes a vector of arbitrary positive constants. Through this formulation, Rochet offers an intuitively appealing interpretation for the optimal risk weights. Since the CAPM implies that all efficient portfolios are located along the capital market line in Equation (7), the bank portfolios in Equation (8) can be made efficient by setting $\boldsymbol{w}$ proportional to $\boldsymbol{r} - r_f$. This proportionality is achieved by setting

$$\boldsymbol{w} = \boldsymbol{\beta} = \frac{\boldsymbol{r} - r_f}{r_M - r_f} \tag{9}$$

Thus, if $\boldsymbol{w}$ is equal to the vector systematic risk coefficients or sometimes called the betas $\boldsymbol{\beta}$ of the assets, a risk-weighted minimum capital requirement does not induce inefficient asset choices by the banks in light of the CAPM. As is well known, these asset betas can be sufficiently easily estimated from data as $\beta_i = \frac{Cov(r_i, r_M)}{\sigma_M^2}$.

To conclude the seminal portfolio literature, Koehn and Santomero (1980) and Kim and Santomero (1988) show a key rationale in applying capital regulation to banks. Simple minimum capital requirements in the form of a leverage ratio constraint can lead to riskier overall bank portfolios. This is because banks are able to substitute leveraging ability to riskier assets in their portfolios. As a consequence, the effect a leverage ratio constraint on the overall riskiness of the banking system depends on the distribution of risk aversity in the banking system. Kim and Santomero (1988) show that these inefficiently risky asset allocations can be fully eliminated by correctly set risk-weighted minimum capital requirements. Rochet (1992) interprets the asset betas of the CAPM as these correct risk weight and criticizes these two papers for assuming that banks are fully liable. When limited liability is correctly taken into account, even the correct risk-weights cannot fully prevent banks from substituting leveraging ability to riskier assets in their portfolios.

4 The Incentive Approach

Another common way of analyzing bank solvency regulation is by considering the incentives of banks. Many shortcomings of the portfolio selection approach have been explored through this approach. As regulators only have limited resources for monitoring banks, one may be interested in studying solvency regulation in a framework where capital regulation is not necessarily hard wired into banks' decision making, and thus can be breached by banks. Along these lines, Milne (2002) argues that the previous literature has failed to sufficiently treat banks as forward-looking optimizers balancing the costs of breaching regulation and benefits of lending choices. Under breachable regulation, the riskiness of banks can be decreased by increasing the severity of penalties levied on regulatory breaches. However, Estrella (2004) contends that these penalties on banks might not be viable as it is not clear how these would be enforced on insolvent banks.

Another shortcoming of the portfolio approach is that the liability structure of banks is often abstracted away from the analysis. Milne (2002) and Estrella (2004) both consider cases where banks can alter the liability side of their balance sheets through debt funding. Estrella analyses a framework where banks have incentives to incorrectly disclose information of their riskiness and demonstrates the difficulties of aligning bank incentives to truthfully disclose information to the regulators. Blum (2008) further studies this principal agent problem of truthful information revealing, and suggests that a leverage ratio requirement gives incentives for banks to correctly reveal their riskiness to the regulatory authority.

Bank incentives have also been explored in models of monopolistic competition. This marks a relaxation of a significant assumption, as banks need not be considered small anymore. Hellmann et al. (2000) analyze a model of monopolistic competition for banks in credit markets. The authors find that the optimal solvency regulation consists of a mix of capital regulation and deposit rate regulation. The next sections cover these incentive-based models of solvency regulation.

4.1 Breachable Capital Regulation

Milne (2002) models solvency regulation as an incentive mechanism that can affect banks' portfolio allocations in a framework where banks are able to breach a risk-weighted minimum capital requirement. In particular, contrary to the portfolio approach which analyzed asset allocations on an aggregated portfolio-level, Milne analyzes the contribution of risk-weights and a penalty on breaching capital requirements on the optimal allocation of each asset separately. In a two-period model Milne begins analysis in the short run where first period bank capital C_0 is exogenous and equity financed at cost r_S and then extends this into a medium-run analysis, where banks can alter C_0 through debt financing at cost r_D.

Banks can invest in a variety of risky assets and liabilities $\boldsymbol{x}$ and in a safe asset x_S with return r_S. The total expected return of each asset/liability of the bank i is divided into the liquid realizable return r_i and the illiquid non-realizable return μ_i, so that the total expected return of asset i is $r_i + \mu_i$. For example, mortgages would have high unrealizable return due to their illiquid nature. The distribution of the realizable and unrealizable returns on asset i is represented by the random variables ε and θ respectively. Regulators set a penalty χ that is imposed on a bank in the case where it breaches the risk-weighted minimum capital requirement. Such a regulatory breach occurs when a bank's end period capital $C_1 = \langle \boldsymbol{x}, \boldsymbol{r} + \boldsymbol{\mu} - r_S \rangle$ is smaller than the risk-weighted minimum capital requirement $\langle \boldsymbol{x}, \boldsymbol{w} \rangle$. Return to bank shareholders in the end-period is

$$V = C_1 - \chi, \quad \chi = 0 \quad \text{if} \quad C_1 \geq \langle \boldsymbol{x}, \boldsymbol{w} \rangle \tag{10}$$

The expected value of V is

$$\begin{aligned} \mathbb{E}[V] &= \mathbb{E}[C_1] - \chi \mathbb{P}[C_1 - \langle \boldsymbol{x}, \boldsymbol{w} \rangle \leq z] \\ &= \mathbb{E}[C_1] - \chi F(z) \end{aligned} \tag{11}$$

The bank maximizes the expected future returns and thus solves this stochastic optimization problem with the cumulative distribution evaluated up to the point where regulatory breach occurs ($z = 0$)

$$\max_{\boldsymbol{x}} E[C_1] - \chi F(z)|_{z=0} \tag{12}$$

The key distinction of this model, compared with the previous portfolio optimization models, is that when the bank maximizes expected returns, it is no longer optimizing subject to an ex-ante binding regulatory constraint. On the contrary, it optimizes expected returns with respect to the ex-post probability of the regulatory constraint being broken $F(z)|_{z=0}$ weighted by the associated penalty χ. The required return on asset i is now given by the first order condition of the optimization problem as

$$r_i + \mu_i = r_S + \chi \frac{\partial F(z)|_{z=0}}{\partial x_i} \tag{13}$$

Equation (13) intuitively tells us that the return $r_i + \mu_i$ on asset i should optimally equal the funding cost r_S and the assets marginal contribution on increasing the probability of regulatory breach weighted by the penalty χ. Milne shows that this first order condition can be explicitly written as

$$r_i + \mu_i = r_S + \frac{\chi f(0)}{1 + \chi f(0)}(w_i \mu_i - \mathbb{E}[\varepsilon_i + (1 - w_i)\theta_i]|_{z=0}]) \tag{14}$$

Using Equation (14), banks can be divided into three meaningful categories with different incentives under the capital regulation. First, a well-capitalized bank has a negligible marginal probability of regulatory breach $f(0)$ and thus the risk weightings w_i only have little impact on its portfolio. Second, a decently capitalized bank has a non-negligible probability of regulatory breach, and its portfolio decisions greatly influence this probability. Thus, $f(0)$ is large and the risk-weights greatly constrain bank portfolio decisions. Last, a poorly capitalized bank finds it highly improbable to avoid regulatory breach by its portfolio decisions. Thus, $f(0)$ is again small and the risk-weights have little effect on its portfolio.

When attention is shifted to the risk weights w_i alone, Milne's analysis suggests that the impact of risk weights on portfolio decisions depend only on factors μ_i and θ which characterize the illiquidity of returns. If the assets are highly illiquid ($\mu > 0$ and $\theta > 0$), the weights w_i greatly constraint portfolio choices. On the contrary, the risk weights create no disincentives to purchasing liquid assets as these assets can easily be sold under the threat of regulatory breach. As the term $\frac{\chi f(0)}{1+\chi f(0)}$ is increasing for all realistic values of the penalty ($\chi \geq 0$), the regulator should set a high enough penalty to give banks incentives to increase their holdings of liquid assets to combat banks' incentives to breach the capital requirements.

Moving from short-term to medium-term analysis, first period capital C_0 is no longer endogenous. In particular, the bank raises C_0 until the marginal cost of expected regulatory breach equals the cost marginal cost of substituting between debt and equity financing $r_D - r_S$

$$\chi \frac{\partial F(z)}{\partial C_0} = \chi f(0) r_S = r_D - r_S \tag{15}$$

Substituting this constraint into Equation (14), the first order condition becomes

$$r^i = r^s - \mu_i + 1/v_i + \frac{r^D - r^S}{r^D}(w^i\mu^i - \mathbb{E}[\varepsilon^i + (1-w^i)\theta^i]|_{z=0}]) \tag{16}$$

The factor differentiating the short-term analysis (Equation 12) and that of the medium-term (Equation 14) is that in the medium-term, the penalty for regulatory breach χ does not affect the portfolio choices of the bank. This is due to banks increasing capitalization to reduce future costs of regulatory breach when raising capital through debt-financing is possible. So, in the medium-term regulators need not worry about regulatory breaches, and in the short term they can respond to high probabilities of regulatory breach by imposing more stringent ex post penalties.

4.2 Risk-Revealing Incentives

As banks operate in a field with large informational asymmetries, it might also be fruitful to study a situation where banks have more information about the riskiness of their balance sheet than the regulatory authority. This approach to studying banks' risk-revealing incentives under solvency regulation is a field of literature that well demonstrates underlying incentives of banks.

Estrella (2004) studies whether banks have incentives to voluntarily disclose their riskiness to regulators. The model is a Bayesian game where banks raise funds through the debt market to fund investments. An implication of this model is that imposing minimum capital requirements bring banks closer to revealing their true riskiness, but this does not fully align bank and regulator incentives. Furthermore, these incentives can fully be aligned by large enough ex-post penalties for regulatory breach as in Milne (2002). This is because banks are indifferent between fully and partially revealing risks when penalties are large enough to fully ward off incentives to breach regulation.

Blum (2008) further studies risk-revealing incentives in a similar setting to that of Milne (2002), and finds that a leverage ratio constraint along the lines of Koehn and Santomero (1980) can make banks reveal their true riskiness to the regulatory authority. This analysis underlies an interesting interpretation of the channel through which minimum capital requirements carry out solvency regulation. When banks take inefficient risks in the absence of regulation, capital requirements force banks to artificially increase their charter value, the present value of future profits, and thus have more capital at risk. Through this capital at risk effect, banks can be incentivized to stop inefficient risk taking.

4.3 Monopolistic Competition

Keeley (1990) contends that the present value of a banks future profits, also called the banks charter value, can decrease due to increased competition in the banking sector. This decreased charter value under competition can lead to banks taking inefficient gambles as they have less to lose, which is called a negative charter value effect. This negative charter value effect works in the opposite direction than the positive capital at risk effect mentioned in the previous section. This important mechanism has thus far been left unexplored as much of the literature on solvency regulation assumes that banks face perfect competition in their respective markets.

Analyzing monopolistic competition for banks in credit markets, Hellmann et al. 2000 discard the restrictive assumption of perfect competition that necessitates the treatment of banks as small price takers. It is a model of moral hazard operating through the charter value effect and it underlies how this charter value effect can be deterred through the value at risk effect. As competition increases, the charter values of banks are eroded. Having less to lose in the case of bank closure, banks have less incentives to act prudentially. In the model, banks compete for deposits by setting interest rates on deposits. The banks can either invest these deposits in a safe asset or gamble on an asset with higher return when the gamble succeeds, but with lower expected return. If such a gamble fails, the bank is closed by the regulators. In the absence of solvency regulation, the existence of a Nash-equilibrium where all banks choose to invest in the safe asset is dependent on the degree of competition in credit markets. When there is enough competition, such a prudential equilibrium does not exist, and banks will take inefficient risk by gambling due to a negative charter value effect.

Hellmann et al. (2000) explore capital regulation through a simple minimum capital requirement as possible way of combatting this excessive risk taking with the the value at risk effect. Contrary to much of the literature assuming perfect competition such as the portfolio approach, they find that while capital regulation can force the bank to stop taking inefficient risks through the capital at risk effect, this is inefficient as capital is costly to the banks. The authors show that through setting an upper bound on deposit rates, the regulator can inflate the charter value of banks by artificially limiting the amount of competition and thus disincentivizing inefficient risk taking. A mix of this deposit rate regulation and capital regulation is found to be the optimal solvency regulation, as it prevents inefficient risk taking of the banks, always Pareto dominates pure capital regulation, and gives the regulators flexibility for maneuvers through the capital requirements.

5 The Agency Problem Approach

Discarding the Arrow-Debreu complete market hypothesis in the portfolio approach allowed us to work around many real-life frictions in financial markets by introducing a set of risk aversions for banks. However, accepting these frictions has the implication that the Modigliani-Miller theorem, which guarantees that a firms ownership structure does not affect the banks valuation (Modigliani and Miller (1958)), also breaks down. Subsequently, the agency problem of conflicts of interest between bank management and ownership deserves attention in the study of bank solvency regulation, something it did not sufficiently receive in the standard portfolio approach [5]. When viewed from this point of view of agency problems, the portfolio approach can be seen as only being realistic when banks are owned and operated by the same persons, as then no conflicts of interest arise between bank management and ownership. This chapter focuses on the implications of discarding this major assumption.

As Jensen and Meckling (1976) and later M. Dewatripont and J. Tirole (1994) argue, equity holders tolerate more risk than debt holders due to the limited liability clause. As a consequence of this, firms might encounter moral hazard problems due to excessive risk taking incentives under equity holder control. Dewatripont and Tirole study this separation of ownership in a model of incomplete contracts by introducing a non-contractible option of continuing or not continuing the banks operations, decided by the party controlling the firm. In this model, firms' operations tend to be inefficiently continued under the ownership of equity holders' control and inefficiently stopped under control of debt holders. M. Dewatripont and J. Tirole (1993) inspect this theory in the context of the banking firm. As a special feature of banks, the debt holders are its depositors. Further, when deposits are insured through a public insurance scheme, the incentives of debt holders are ultimately represented by the taxpayers who pay for the losses in the case of bank insolvency.

M. Dewatripont and J. Tirole (1993) contend that the separation of bank ownership and management results in inefficiencies that create the necessity for bank solvency regulation. They argue that capital requirements fail to account for the agency costs and suggest a solvency regulation framework where the control rights of the bank are correlated with bank performance to decrease the agency costs. When the bank does well, the manager should be rewarded for their effort by equity control of the bank. Correspondingly, control should be given to debt holders under poor performance to give the manager sufficient incentives not to shirk. In the next sections this model of

[5] See Jeitschko and Jeung (2005) for a more recent treatment of agency problems in the portfolio approach.

incomplete contracts and its implications are further explored.

5.1 Incomplete Contracts

In order to keep the analysis sufficiently dense, this section takes inspiration from a simplified interpretation of M. Dewatripont and J. Tirole (1993) by Freixas and Rochet (2008). In the model at time 0 the bank uses deposits D_0 and equity E_0 to acquire loans $L_0 = D_0 + E_0$. Managers operate the bank with an effort level e, which costs them c. Higher effort by the manager is correlated with better quality loans. To simplify the analysis, this effort can either be sufficient $e = \bar{e}$ or insufficient $e = \underline{e}$. At time 1 the first payment v from the loans is obtained and a signal u of the future charter value η is observed. The effort level exerted by the manager is positively correlated with v and u, but v and u are assumed independent to keep the argument simple. After observing these signals, the controlling party of the bank decides on an ex-ante non-contractible action A on whether to continue operations or to stop and liquidate the bank and receive the charter value η. This action of continuing or stopping is denoted $A \in \{C, S\}$, and determines the conditional distribution of η on u: $H_A(\eta|u)$.

From the point of view of bank outsiders, the incremental expected profit for continuing at time 1 is the difference between profits from continuing and stopping

$$\Pi(u) = \int_0^\infty H_C(\eta|u)\, d\eta - \int_0^\infty H_S(\eta|u)\, d\eta \tag{17}$$

For continuing to be the efficient action, it is necessary that $\Pi(u) \geq 0$. Assuming that Π is increasing in u, we are guaranteed to have $\hat{u}$ such that $\Pi(\hat{u}) = 0$ and it is only optimal to continue if $u \geq \hat{u}$ and to stop when $u \leq \hat{u}$

Taking into consideration the incentives of the managers, this decision rule needs to be adjusted with the costs and benefits of the manager. In line with previously presented literature on solvency regulation, we set up a maximization problem of the banks' profits, with the notable exception of a incentive compatibility constraint for the manager. Let $x(u, v) = \mathbb{P}(A = C|v, u)$. Now the profit maximization problem with respect to this probability of continuing given the signals u and v can be expressed using the conditional probabilities of the signals given optimal effort by the manager $\bar{e}$

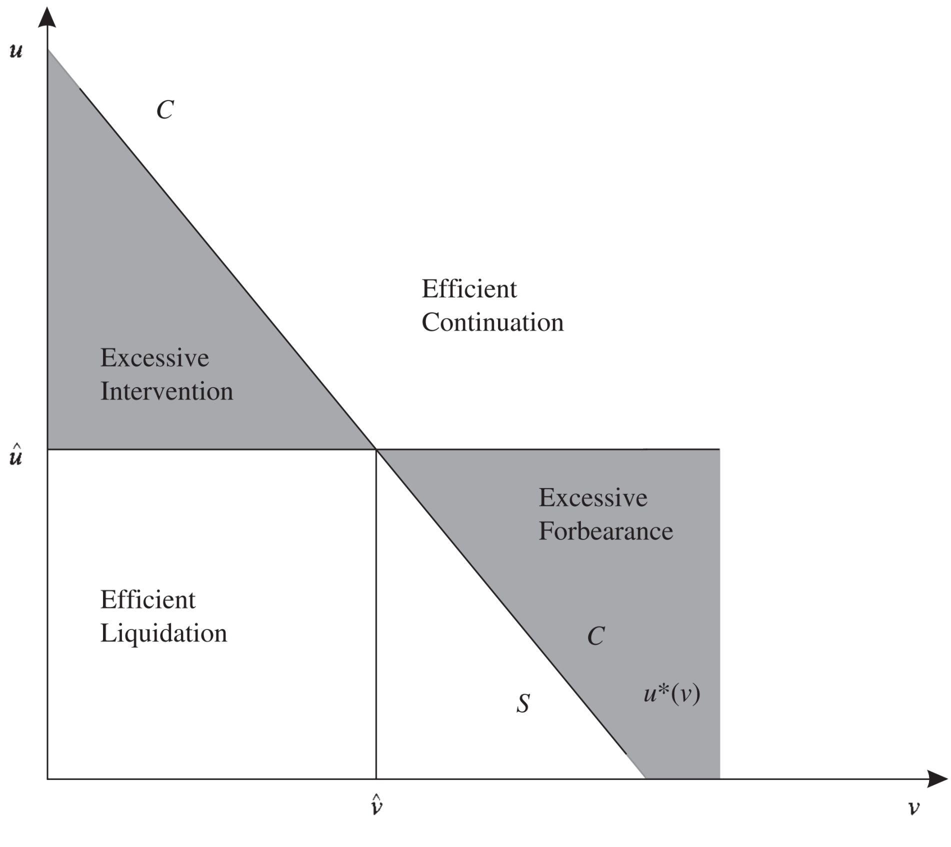
$$\max_{x \in [0,1]} \int_0^\infty \int_0^\infty \Pi(u) x(u, v) \mathbb{P}(c|\bar{e}) \mathbb{P}(v|\bar{e})\; du\; dv \tag{18}$$

Subject to the constraint that the manager will want to exert optimal effort and thus has private benefit B from the bank continuing larger than the private cost of effort c

$$B \int_0^\infty \int_0^\infty x(u,v)[\mathbb{P}(c|\bar{e})\mathbb{P}(v|\bar{e}) - \mathbb{P}(c|\underline{e})\mathbb{P}(v|\underline{e})]\, du\, dv \geq c \tag{19}$$

Solving this equation, Dewatripont and tirole show that there exists a solution $u^*(v)$, where u^* is decreasing in v. As the outsiders optimal solution $\hat{u}$ is a constant and $u^*(v)$ is a strictly decreasing function, they only align at a single point, denotes $(\hat{u}, \hat{v})$. This is further elaborated by Figure 2, which graphically illustrates the differences between the optimal and incentive compatible decision rules, $\hat{u}$ and $u^*(v)$ respectively.

Figure 2: Optimal and incentive compatible decision rules (Xavier Freixas and Jean-Charles Rochet (2008). "The Regulation of Banks". In: *Microeconomics of Banking*. 2nd ed. Cambridge, Massachusetts: The MIT Press, pp. 305–340)



By threatening the manager by debt control of the bank for $v < \hat{v}$ and equity control of the bank for $v > \hat{v}$, the incentives of management and the optimal decision rule can be aligned. Let $\tilde{D}$ be the fraction paid out to depositors from the realized η. Then the expected profits for continuing for depositors and equity holders are

$$\Pi(u, \tilde{D})_D = \int_0^{\tilde{D}} H_S(\eta|u)\, d\eta - \int_0^{\tilde{D}} H_C(\eta|u)\, d\eta \tag{20}$$

$$\Pi(u, \tilde{D})_E = \int_{\tilde{D}}^{\infty} H_S(\eta|u)\, d\eta - \int_{\tilde{D}}^{\infty} H_C(\eta|u)\, d\eta \tag{21}$$

Which communicates the incentives of each party to continue. Say the debt holders were to have control of the bank. Now make the logical assumption that a better signal u is associated with a higher probability of continuing $\frac{\partial}{\partial u}(H_s - H_C) > 0$. This has the implication that depositors and equity holders see their incentives to continue operations increase in u for any given v, as can be seen from Equation (18) and Equation (19). This means that the implementation of u^* necessitates that $\Pi_D(u^*(v), \tilde{D})_D = 0$, which can be seen from the graphical argument in Figure 2. Dewatripont and Tirole show that whenever this is satisfied, it will always be the case that the realized v is smaller than $\hat{v}$. Thus, depositors only implement u^* when $v < \hat{v} \Rightarrow \Pi(u) > 0$, a manifestation of the depositors' excessive incentives to interfere. Replicating the same argument for the equity holders, Dewatripont and Tirole find that equity holders only implement u^* when $v > \hat{v} \Rightarrow \Pi(u) < 0$ demonstrating the equity holders' excessive incentives for forbearance.

Because depositors have incentives to excessively intervene and stop operations and equity holders have incentives to be excessively forbearing and continue operations, the optimal solvency regulation scheme consists of depositors taking over the bank's operations in turbulent times $v < \hat{v}$ and equity holders having control otherwise. This threat of depositor control in turbulent times gives management incentives to exert the optimal amount of effort. The rationale for this is clear-cut: As equity holders are biased towards the managers incentives and depositors have opposite incentives with the managers, the managers should be punished for lower values of v (higher probability of shirking) by depositor control and rewarded for higher values of v (lower probability of shirking) with equity control of the bank.

5.2 The Depositors' Representative

The depositors, which are also the debt holders of a bank, are small and dispersed. It may thus be infeasible for them to organize control of the bank for low values of v due to informational and free riding problems. As a solution to this, M. Dewatripont and J. Tirole (1993) suggest that a regulatory agency should act as the depositors' representative in taking control of the bank when the bank performs poorly.

This suggestion echoes real-world instances where regulatory agencies have taken control of poorly performing banks, for example with capital injections. There however is a subtlety differentiating the policy recommendation and some of the real-world comparisons. It would seem intuitive for a regulatory authority to maximize social welfare when it takes control of the bank. The previous analysis nonetheless has the major implication that for ex-post optimality, the regulatory authority needs to ex-ante commit to operating under the depositors' incentives. Otherwise, managers are not ex-ante faced with strong enough incentives to exert optimal effort, and the bank will have a higher probability of insolvency due to a worse quality of acquired loans. To construct the optimal incentive scheme for solvency regulation, the regulatory authority should thus be given a mandate that is fully monetary and neglects social welfare considerations.

6 Discussion

As mentioned in the introduction, the core of the current global solvency regulation framework consists of the three Basel Accords of 1988, 2004, and 2011. The theories of banks solvency regulation present a wide array of potential policy implications that partly reflect the methods currently in use under the Basel Framework[6]. Since the first Basel Accord, risk-weighted capital requirements, presented in the portfolio approach by Kim and Santomero (1988) and Rochet (1992), have been at the core of the prevailing bank regulation framework. Under the current Basel III framework, banks are required to have at least 8% of regulatory capital out of total risk-weighted assets.

After the second Basel Accord, banks have been allowed to internally estimate the riskiness of assets through an Internal Rating Based (IRB) approach. These risk assessments have been the underpinning of the formation of risk weights in current minimum capital requirements. The IRB approach has been criticized for shortcomings of the underlying value at risk (VaR) methodology for example by Kretzschmar et al. (2010). Arguably more important to the current analysis, Blum (2008) also criticizes the IRB approach for assuming that banks have incentives to truthfully reveal their risks to the regulator. Nonetheless, Blum contends that this adverse effect can be prevented by implementing a simple leveraging constraint. This constraint, also studied by Koehn and Santomero (1980), is incorporated in the current Basel Framework as a 3% minimum leverage ratio. This leverage ratio can be viewed as an independent from the risk-weighted minimum capital requirement and thus acts as a fail safe for modelling risks in the IRB approach.

Other more nuanced requirements under Basel III, such as the liquidity coverage

[6]A complete review of all the covered aspects of the Basel framework can be found at Bank for International Settlements (BIS) (2022).

ratio which requires banks to hold enough liquid assets are only partly echoed by the realizable return argument of Milne (2002), which asserts that banks prefer to hold liquid assets to ward of risks of regulatory breach. Another new feature of the Basel framework, countercyclical capital requirements that address the procyclicality of bank capital (Jokivuolle et al. (2014)), is also unrepresented in the presented literature.

Theory seems to also suggest that deposit rate regulations present a potentially viable instrument in preventing inefficient risk taking under monopolistic competition, but this is not reflected in the Basel Framework. VanHoose (2007) argues that empirical evidence of deposit rate regulation working in practice is slim. As an example, Regulation Q, a Federal Reserve Board rule that prevented banks from paying interest on demand deposits in the US was repealed in 2011. The deposit rate regulation scheme of Regulation Q has been criticized for artificially creating substitutes for demand deposits that could pay interest, such as money market mutual funds (Lucas (2013)).

It is important to note that the implications of actual implementations of solvency regulation cannot be fully explained by the very setting specific and generalized partial equilibrium models that abstract away many real-world imperfections. Nonetheless, the models presented do shed light on many key mechanisms, through which solvency regulation is used to mitigate losses by preventing excess risks building up in the banking system.

7 Conclusion

How do banks behave under solvency regulation and what are the optimal forms of regulation to prevent inefficient behaviour by the banks? The literature on bank solvency regulation is a large body of literature, which offers many divergent explanations of bank behaviour and conclusions on the correct methods of solvency regulation. These vary greatly depending on the setting that researchers choose emphasize. This thesis has covered these main theories that necessitate the regulation banks and the optimal solutions to these through solvency regulation.

In the standard portfolio approach, banks' portfolio selection is viewed through mean-variance asset optimization. Literature on the portfolio approach considers capital regulation as a way of preventing excessive risk taking that deposit insurance schemes create by distorting bank incentives. Imposing capital regulation through a leverage ratio does alter the composition of risk in bank portfolios and in the banking system, but the direction of this effect on the total riskiness is ambiguous. To overcome this ambiguity, a risk-weighted minimum capital requirement can be implemented. Risk weights that accurately correspond to the underlying riskiness of assets are needed to extract the full potential of the capital requirement. Many fragile assumptions however leave the portfolio approach susceptible to criticism.

When the scope of research is extended into the incentive structures of banks, models usually conclude that capital requirements do not alone form sufficient basis for optimal solvency regulation. The optimal solvency regulation is often found to be some form of combination of capital regulation and another form of regulation relating to the mechanism under study. This is due to many of the assumptions of the portfolio models neglecting important channels of banks reactions to regulation. These include debt-financing, breachable capital requirements, information revealing, and charter value effects under monopolistic competition. This highlights the multitude of effects that need to be considered when applying solvency regulation. It is important to note that the incentive approach often emphasizes a very specific mechanism and thus direct extrapolations to more general settings, such as the general riskiness of the banking system, ought to be left for models that consider a wider array of factors.

Placing emphasis solely on the agency costs that arise from conflicts of interest between management and owners, the literature emphasizes a totally different set of underlying mechanisms for why banks need to be regulated. The separation of bank ownership and management creates the necessity for bank solvency regulation through the differing incentives of bank management and ownership. Under this framework the optimal solvency regulation entails threatening managers with more austere depositor control of the bank under poor performance. If the depositors are not able to organize exercising their control rights, a public agency should be designated as the depositors' representative.

Moving forward from the literature on the defining mechanisms of bank solvency regulation, newer research has, among many things, explored systemic risks in the banking system through macroprudential regulation and developed more realistic models of the computation of risk-weighted assets (RWA) used in minimum capital requirements. As this thesis covered the microeconomic foundations of solvency regulation - and thus covered microprudential regulation - the reader may subsequently be inclined to find research on macroprudential regulation, a strand on bank solvency regulation which considers systemic risks in the banking system. For surveys on macroprudential regulation and systemic risks, see Galati and Moessner (2013) and Benoit et al. (2017). This thesis covered the important risk-weighted minimum capital regulation at a level which fully abstracted from the internal rating based (IRB) approach actually used by banks to calculate the risk weights. For a more careful treatment of RWA in the more appropriate context of an IRB approach - the reader may see for example Cuoco and Liu (2006).

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