Systemic Risk and Optimal Regulation

The effects of Basel III requirements

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Summary

The focus of the present paper is the topic of financial stability and the effects of existing regulation mechanisms. Investment decisions made by financial institutions generate aggregate risk, which poses a threat of systemic collapse. Conceptually this process has been regarded as a negative externality. The present thesis explores to what extent the Basel III requirements provide optimal microprudential regulation and are able to secure financial stability. This is done by the means of a theoretical model representing an aggregation of banks that differ in their ability to handle risk, which cannot be improved upon. Each bank has a choice between safe and risky investments and has to make a decision on the proportion between the two alternatives in the asset portfolio. The risky asset generates a higher return, but increases the probability of going bankrupt for an individual bank. The aggregate amount of investment in the risky asset determines the level of systemic risk. At the same time banks may decrease the probability of going bankrupt by increasing the proportion of equity in the liability structure. However, this is associated with a cost, because investors demand a higher return on capital than on demand deposits. It is suggested that investors may pose "market capital requirements": demand more equity if a bank increases the amount of risky investment. The problem is formalized mathematically as a Net Present Value function that each bank seeks to maximize.

Given the model above, three different regulation mechanisms are considered with reference to the Basel III Accord: the liquidity ratio, risk-weighted capital requirements and the leverage ratio. The regulation alternatives are formulated mathematically and the problem is solved by the means of control theory, where the social planner finds an optimal path of liquidity and capital requirements. Specifically, it is shown that under perfect information Pareto optimality may be achieved with the help of a combination of liquidity regulation and risk-weighted capital requirements that both decrease in risk handling ability. In other words, banks that are good at risk handling are allowed to hold less liquidity and less capital as a fraction of their assets and liabilities respectively. Under asymmetric information, however, financial institutions that are bad at risk handling acquire incentives to mimic institutions that are good at risk handling in order to increase their revenues and save on capital. Such incentives are strongest when liquidity regulation is used in a combination with either the leverage ratio or risk-weighted capital requirements that decrease in risk handling ability. In

order to prevent excessive aggregate risk accumulation and secure financial stability, the regulators may choose to equalize liquidity requirements for banks with different risk handling ability and use the latter in a combination with the leverage ratio. This results in inefficient risk sharing, suboptimal liquidity and capital buffers, at least for some banks. Alternatively, the regulators may choose to use liquidity requirements that decrease in risk handling ability in a combination with equal capital requirements for all banks. Depending on the strictness of the latter this may result in suboptimal liquidity and capital buffers, inefficient risk sharing or contribute to general underinvestment. The thesis thus shows that when the main source of heterogeneity across financial institutions is the ability to handle risk, the existing regulation requirements cannot achieve the first-best solution. In particular, they always produce suboptimal capital and/or liquidity buffers, at least for some banks. This is because financial stability is secured through what is known as "bunching": treating different financial institutions alike.

Since the latest Basel Accords are expected to be fully implemented in 2018, the predictions of the model are compared to the currently observed trends in the financial sector. Specifically, it has been noted that because of stricter risk-weighted capital requirements introduced by Basel III, banks have started a process of derisking of their assets. This might be an indicator of movement towards greater financial stability. At the same time concerns have been expressed as to whether financial activity may be simply migrating to the unregulated non-bank sector. Moreover, it is debated whether risk-weighted capital requirements introduced by Basel III are strict enough and will be able to combat excessive risk taking. Finally, it is uncertain whether Basel III has succeeded in providing incentives for truthful revelation of information. As long as banks have mimicking incentives, they will try to use any kind of "cosmetic adjustments" in order to maximize their profits at the cost of financial stability, which has been illustrated by the present thesis.

Preface

I would like to thank my supervisor, Jon Vislie, for his help, support and inspiration. All mistakes in the present thesis are my responsibility.

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1 Introduction

Since the global financial crisis of 2008 the concept of financial stability has attracted a lot of attention of theoreticians and policy makers. Generally financial stability has been defined as *"the absence of imbalances in financial markets"* (2003, Foot quoted in Haugland, Vikøren, 2006, p. 26) or as a "*condition in which the financial system – comprising of financial intermediaries, markets and market infrastructures – is capable of withstanding shocks*" ([European Central Bank](#), 2014). The incidence of the latest financial crisis has once again demonstrated that market outcomes are inefficient posing a threat of systemic risk accumulation. Even individual bank failures *"could set off a chain reaction that may undermine the stability of the financial system"* (Berger et al., 1995, p. 17). The latter may affect sustainable economic growth and development and generates in any case a social cost in form of an economic downturn. The existence of systemic risk may therefore justify regulation of the financial sector provided that it *"can improve efficiency in a way that outweighs the costs of regulation"* (Borchgrevink et al., 2013, p. 1). At the same time the view that financial regulation is desired is not shared universally. Diamond and Rajan (2001) argue, for instance, that financial fragility is actually necessary, because it disciplines banks, while regulation may harm the economy. Nevertheless, policy makers have made several attempts at creating global regulatory framework, the most extensive being the Basel Accords. Its goal is to *"ensure that financial institutions internalize the risks and explicit or implicit costs of their business activities"* (International Monetary Fund [IMF], 2012, p. 76), so that the financial sector becomes safer and more sound. Expected to be fully implemented by 2018 the latest Basel III requirements have already been subject to discussions as to whether the financial sector is indeed heading in the direction of greater financial stability.

The purpose of this thesis is to conduct theoretical modeling of the financial sector in order to discuss possible effects of the new regulation standards and compare those to currently observed trends. This is an uneasy task, since the financial system is inherently complex and every financial institution is faced with a large number of choice variables in its decision-making process. As pointed out by Stiglitz and Greenwald (2003, p. 49), *"given its equity, the bank must decide how much to lend, how thoroughly to screen loan applicants, how much to retain in government T-bills, how many funds to acquire through deposits, what interest rate to charge on loans, and what interest rate to pay on deposits"*. Only some of these issues will be dealt with in the present thesis, and the modeling choice has been based

on the belief that *"capital and liquidity requirements are the main staple of financial regulation"* (Brunnermeier et al., 2009, p. 45). Hence, the thesis focuses on microprudential regulation carrying the idea that *"the robustness of the system as a whole is related to the strength of its individual members"* (Goodhart et al., 2004, p. 597).

To begin with, a comprehensive literature review on the topic of financial stability and bank regulation will be presented. Some background information on the already existing regulation of the financial sector will be given with the focus on the Basel Accords. Thereafter, a mathematical model representing an aggregation of banks will be outlined. Inspired by an article by Perotti and Suarez, the model will represent a reformulation and extension of their work. The main idea behind the theoretical construction in the present thesis is that the source of heterogeneity across financial institutions is the *ability* to handle risk that cannot be improved upon. Given the latter, each bank decides on the amount of risk in its asset portfolio, while the aggregate amount of investment in the risky asset defines the level of systemic risk. This model will be applied to illustrate several of the newest regulation mechanisms concerning both assets and liabilities as presented by the Basel III Accord, namely the liquidity coverage ratio, risk-weighted capital requirements and the leverage ratio. It will be shown that liquidity regulation in a combination with risk-weighted capital requirements can secure Pareto efficiency under perfect information. Under asymmetric information, however, banks will acquire incentives not to reveal their risk handling ability truthfully in order to generate higher profits. Specifically, it will be demonstrated that optimal liquidity regulation in a combination with the leverage ratio always gives banks mimicking incentives. The subsequent adjustment of risky investment as a result of such mimicking leads to a system collapse due to aggregate risk accumulation. In the case of risk-weighted capital requirements two possible alternatives will be treated: one where risk-weighted capital requirements decrease in risk handling ability and the other where risk-weighted capital requirements are set at the same level for all banks. The first case will turn out to produce same mimicking incentives and lead to excessive aggregate risk accumulation, while the second case may secure financial stability provided that capital requirements are set at a high enough level. The latter alternative will nevertheless generate a tradeoff, since banks that are good at risk handling will acquire an incentive to reduce their risky investments due to strictness of capital requirements. Finally, the thesis will compare predictions of the theoretical model with currently observed trends from the latest reports on financial stability

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and discuss topics of optimal liquidity and capital buffers and efficiency of risk distribution as well as migration of financial activity to the non-bank sector.

2   Literature review

Within the topic of financial stability it has been common to distinguish between individual bank crises and system collapse as a result of aggregate risk accumulation. The latter is often formally presented as a negative externality arising, for instance, due to high riskiness of banks' assets, excessive reliance on short-term funding or banks' lending decisions. The existing regulation requirements aim both at making individual institutions more sound and the financial network as a whole safer. The following literature review presents models and contributions on bank crises and systemic risk modeling and proposed regulation mechanisms that could secure financial stability.

One strand of theoretical literature focuses on the problem of liquidity as a primary source of financial instability. A paper by Perotti and Suarez that inspired the present thesis constructs a model, in which *"short-term funding enables credit growth but generates negative systemic risk externalities"* (Perotti, Suarez, 2011, p. 3). The authors suggest that by borrowing short banks are subject to refinancing risk, because *"sudden withdrawals may lead to disruptive liquidity runs"* (ibid., p. 4). The paper proposes liquidity regulation as a solution to such risk and compares the effectiveness of price and quantity mechanisms. It turns out that when *"banks differ only in capacity to lend profitably"* (ibid., p. 5), the regulator may effectively use Pigovian taxation in order to correct for the existing externality. On the other hand, when banks differ in risk-taking incentives, *"such gambling incentives are not properly deterred by levies, while quantity constraints are more effective"* (ibid., p. 6). An influential paper by Diamond and Dybvig (1983) points out that financial institutions suffer from a maturity mismatch investing long and borrowing short. A crisis in form of a bank run may happen when *"sudden withdrawals can force the bank to liquidate many of its assets at a loss and to fail"* (Diamond, Dybvig, 1983, p. 401). When such withdrawals first start, banks will use their liquidity buffers and if those turn out to be insufficient, they will be forced to liquidate long-term assets. Since the latter can only presumably be done at some cost, the bank may go bankrupt if too many long-term assets are sold. Under this set-up bank runs are a type of Nash equilibrium, so that *"even "healthy" banks can fail"* (ibid., p. 402). The idea of crisis as an equilibrium is also found in other papers, such as that by Morris and Shin (2008, p. 239), who regard systemic collapse as a coordination failure and argue that *"policies that lower coordination threshold or the cost of miscoordination are likely to promote system stability"*. In the Diamond Dybvig model, however, *"it is only by coincidence that runs are*

experienced by several banks at the same time" (Allen, Gale, 2007, p. 149), so the idea of systemic risk is not explicitly elaborated on. Allen and Gale (2007, p. 83) outline an alternative formulation of the Diamond Dybvig model, in which bank runs are *"a natural outgrowth of weak fundamentals arising in the course of a business cycle"*. In an economic downturn, if depositors start worrying that returns on assets may be significantly lower than expected, they will withdraw their money creating panic. In this view crises are *"an integral part of the business cycle"* (ibid.). A paper by Rochet and Vives (2004, p. 5) *"builds a bridge between the "panic" and "fundamentals" view of crises by linking the probability of occurrence of a crisis to the fundamentals"*. The authors argue for the existence of unique equilibria when investors have precise information about the condition of banks' assets. However, when such information is uncertain and subject to speculation, *"there is the potential for a coordination failure"* (Rochet, Vives, 2004, p. 5). In terms of regulation the paper suggests that *"liquidity and solvency regulation can solve the coordination problem but typically the cost is too high in terms of foregone returns"* (ibid.). Of this reason regulation must be complemented with some sort of emergent help mechanisms.

An alternative approach to financial stability is presented in a number of papers that relate it to banks' investment decisions, particularly the riskiness of assets. A paper by Coulter, Mayer and Vickers (2013) sets up a model, in which banks choose between safe and risky investment alternatives. The latter decision generates systemic risk externality, but the level of aggregate risk may be lowered by increasing the amount of equity on the liability side. The paper shows that under some conditions, such as perfectly correlated risks of failure and no bail-outs, both taxation and capital requirements correct the externality equally well. However, *"taxation increases debt funding needed per loan, which could exacerbate rather than diminish potential externality problems"* (Coulter et al., 2013, p. 2). Moreover, the authors argue that systemic risk in the financial sector has certain special features, which make it different from other types of negative externalities. Of this reason taxation and regulation are not equivalent and *"the conventional preference for capital regulation over taxation has a sound underlying rationale"* (ibid.). A preference for capital regulation is also shared by Rafael Repullo (2002), who presents a dynamic model where banks can invest in two alternatives: safe and risky. Under this set-up two different equilibria are possible, defined as "prudent" and "gambling", and their incidence depends on the level of competition among banks. In very competitive and very monopolistic markets only the gambling equilibrium exists, but in intermediate markets both types of equilibria are possible. Repullo

(2002, p. 21) considers capital requirements and deposit ceilings as regulation alternatives and suggests that *"the former are always effective, while the latter may not always work"*. Koehn and Santomero (1980) examine the effect of capital requirements on the riskiness of the asset portfolio chosen by an individual bank. They set up a maximization problem, in which banks find an optimal fraction of equity to risky investment. The social planner then introduces flat capital requirements in order to *"lower probability of failure"* (Koehn, Santomero, 1980, p. 1243). The authors show that depending on how risk averse an individual bank is, some banks may increase the amount of risky investments. This produces perverse effects in the model, since under certain conditions *"the relatively safe banks become safer, while risky institutions increase their risk position"* (ibid.). Santomero and Watson (1977) point out that capital regulation may involve a tradeoff between *"the marginal social benefit of reducing the risk of the negative externalities from bank failures and the marginal social cost of diminishing intermediation"* (Herring et al., 1995, p. 22). Blum (1999) treats the effect of capital on assets in a dynamic setting where banks are allowed to make investments in the first two periods. Depending on whether capital regulation is introduced in the second or the third time period, this has an effect on the asset composition. Specifically, introduction of capital requirements in the third (and the last) period leads to *"an increase in risk"* (Blum, 1999, p. 755). Gorton and Winton (1995) propose a multi-period model of banking that is solved through backward induction. The aggregate risk in the model presents itself as a sudden event and its overall level becomes known, *"even though which individual banks have losses is not known"* (Gorton, Winton, 1995, p. 8) until some further date. Banks may restructure their portfolios in response to this information. The paper seeks to outline optimal capital requirements *"with the aim of reducing the chance of an individual bank failure and thus enhancing the overall stability of the overall banking system"* (ibid., p. 1). The authors come to a conclusion that not all banks may adhere to the rules, but under certain conditions the *"regulator may find it optimal to pursue policies that resemble "forbearance" – i.e. the regulator does not close banks that have a low or negative net worth"* (ibid., p. 3). Moreover, the paper shows that raising additional capital inflicts costs on other parts of the economy, and *"these costs may lead the regulator to set a capital standard lower than that called by stability considerations alone"* (Santos, 2000, p. 14). A paper by Kashyap et al. (2010) examines the cost effect of raising capital requirements through analyzing existing empirical evidence. The authors conclude that in the short-run increased capital requirements will *"lead to a contractionary effect on the lending activity"* (Kashyap et al., 2010, p. 2), because banks

will choose to adjust through decreasing their assets rather than increasing equity. In the long-run, however, the paper argues on the basis of the Modigliani-Miller theorem that even significant increases in capital requirement will lead only to small changes in *"the borrowing costs faced by banks' customers"* (ibid.). Hence, it is competition in the financial sector and not equity cost that makes banks take up more risk.

Another strand of literature on financial stability suggests that the main source of systemic risk may be financial interconnectedness. Acemoglu et al. (2003, p. 24) examine *"the relationship between the structure of the financial network and systemic risk"*. The authors distinguish between complete and incomplete structures and argue that financial stability may be secured by different structures depending on the number of idiosyncratic shocks. Specifically, if the number of *"negative shocks is below a critical threshold, a more equal distribution of interbank obligations leads to less fragility"* (ibid., p. 24). For a large number of negative shocks the opposite is true, according to the paper. The authors argue that there exists *"financial network externality"* (ibid., p. 25), when banks *"do not take into account the fact that their lending decisions may also put many other banks ... at a greater risk of default"* (ibid.). A similar model proposed by Allen and Gale focuses on *"contagion through interlinkages"* (2007, p. 261) and distinguishes between complete and incomplete structures in a similar manner. The authors conclude that the incomplete structure of financial network *"promotes possibility of contagion"* (ibid., p. 282), while the complete structure *"has equilibria with and without contagion and provides a weaker case for the likelihood of contagion"* (ibid.).

3 The Basel Accords

Regulation of the financial system has a long history. In fact, *"production of (private) money has always been taxed, the seigniorage or monopoly premium on coins being the property of the government"* (Rochet, Freixas, 2008, p. 305). In the recent years various rules for financial institutions have become so numerous and extensive that banking has been called *"one of the most regulated industries in the world"* (Santos, 2000, p. 1). One of the reasons for that is a sudden increase in the incidence of financial crises often linked to preceding liberalization of the financial sector. Until the early 1970s banks were seen as *"akin to public utilities, not commercial entities – boring, uninnovative, but safe"* (Goodhart et al., 2004, p. 594). The onset of liberalization gave rise to several booms in the industry, but ended each time in a subsequent bust. The first global attempt to increase soundness of the financial system started with the establishment of the Basel Committee on Banking Supervision (BCBS) and the conclusion of 1988 Basel Accord on capital standards later extended to Basel II and Basel III regulation requirements. The Accords were concluded and function on a purely voluntary basis representing soft law. However, *"if a country refused to abide by the Accords of the BCBS, the banks of that country could have their branches, and/or subsidiaries, banned from operating in the main financial centers"* (ibid., p. 596).

The primary goal of the first Basel agreement was harmonization of capital standards in response to *"concern about international banks' financial health … and complaints of unfair competition"* (Santos, 2000, p. 17). Targeting the liabilities was considered important for *"maintaining solvency of the regulated institution"* (Morris, Shin, 2008, p. 230). Capital was categorized into two elements: Tier 1 and Tier 2. The former consisted of equity and disclosed reserves, while the latter could, for instance, include hybrid debt capital. Later amendment to the first Basel Accord defined Tier 3 capital that allowed use of subordinated debt. With the capital definition in place the framework required that *"the target standard ratio of capital to risk weighted assets should be set at 8%"* (Basel Committee on Banking Supervision [BCBS], 1988, p. 14) for banks with an international presence. Four different risk weights, also called buckets, were designed and attached to on-balance sheet assets, while *"off-balance sheet contingent contracts, such as letter of credit, loan commitments and derivative instruments … needed to be first converted to a credit equivalent and then multiplied by the appropriate risk weight"* (Santos, 2000, p. 17). This became known as the Standardized approach criticized immediately for *"treating all banks alike and not giving*

safer banks the incentive to distinguish themselves from riskier ones in order to save on capital" (ibid., p. 19). The Accord was amended in 1996 allowing banks to use their internal models to determine required capital needed to cover risks and estimate the individual probability of default. Even though it was observed that *"the introduction of Basel I was followed by an increase in capital ratios"* (Jablecki, 2009, p. 20), this proved to be insufficient in order to guarantee financial stability.

The search for mechanisms that would improve banks' risk management and secure truthful revelation of risks led to a proposal to revise the original Basel Accord. This prompted an introduction of the Basel II framework based on three pillars: minimum capital standards, a supervisory review process and effective use of market discipline (BCBS, 2006). The first pillar aimed at *"making capital charges more correlated with the credit risk of the bank's asset"* (Santos, 2000, p. 21). To this end a new Internal Ratings-Based Approach (IRBA) was introduced allowing banks to estimate their own probability of default that could be converted to minimum capital requirements. The underlying idea was that *"banks have better information regarding their own risks and returns than the regulator does"* (Rochet, Freixas, 2008, p. 323). Thus, Basel II permitted banks *"a choice between two broad methodologies for calculating their capital requirements for credit risk"* (BCBS, 2006, p. 19): a somewhat modified Standardized approach or the IRBA. The second pillar consisted of monitoring process in order to *"ensure that a bank's capital position is consistent with its overall risk profile and enable early intervention"* (Santos, 2000, p. 21). Its goal was to prevent capital from falling below some minimum level. Finally, the third pillar sought to *"encourage market discipline by developing a set of disclosure requirements"* (BCBS, 2006, p. 226) allowing *"market participants to assess key pieces of information on the scope of application, capital, risk exposures, risk assessment processes, and hence the capital adequacy of the institution"* (ibid.). With such information publicly available market participants were encouraged to influence banks' risk management in a manner of a natural regulation mechanism. However, also these requirements proved to be insufficient: *"many institutions had equity amounting to 1-3% of their balance sheets even as they were vaunting themselves as having 10% "core capital"* (Hellwig, 2010, p. 3), and various sorts of adjustments became widespread.

Recognition of the shortcomings of the Basel II framework in the aftermath of the latest financial crisis led to a new revision process and the introduction of the Basel III

regulatory standard aimed at extension of previous requirements. Insuffiency of existing capital buffers was ascribed to *"various deficiencies of risk models and risk management"* (Hellwig, 2010, p. 5). Several new mechanisms were proposed as a strategy of improving matters. To begin with, the new framework launches harmonization of the definition of capital specifying explicitly types of capital allowed in the two Tiers and abolishing the concept of Tier 3. The new capital requirements raise the amount of common equity in the previous risk-weighted requirements and introduce additional buffers, such as "capital conservation buffer", ensuring *"build-up of adequate buffers above the minimum that can be drawn down in periods of stress"* (BCBS, 2011, p. 6). As an additional measure against insufficiency of bank capital the Basel III framework introduces the concept of the "leverage ratio", defined as the proportion of Tier 1 capital to total consolidated assets, and set at the 3% level. Moreover, the new regulatory standard addresses the issue of procyclicality underlining that *"one of the most destabilizing elements of the crisis has been the procyclical amplification of financial shocks throughout the banking system, financial markets and broader economy"* (ibid., p. 5). This is dealt with through introduction of counter-cyclical capital buffers that can *"achieve the broader macroprudential goal of protecting the banking sector in periods of excess aggregate credit growth"* (ibid., p. 7). Finally, one of the biggest innovations in the new regulatory framework has been regulation of liquidity through the "liquidity coverage ratio" and the "net stable funding ratio". The former ensures that every financial institution has *"sufficient high-quality liquid assets to survive a significant stress scenario lasting for one month"* (BCBS, 2013, p. 1), while the latter seeks to *"provide a sustainable maturity structure of assets and liabilities"* (ibid.). Liquidity dry-up has been pointed out as a decisive factor in the unraveling of the latest financial crisis. The two regulation mechanisms aim at preventing situations of bank runs where illiquid banks may become insolvent due to liquidity shortages. Thus, the new liquidity requirements may reflect the idea that *"the traditional approach to financial regulation, based on institutional solvency and identifying solvency with equity capital, has come up short in its assigned task of ensuring system stability"* (Morris, Shin, 2008, p. 230).

4 Model

4.1 Assumptions

Suppose that a bank can invest a fraction of its assets in either a safe liquid asset that, for instance, could correspond to government bonds or a risky illiquid asset u that could correspond to mortgages issued to private persons and enterprises. For simplicity it is assumed that only the risky asset generates a positive return, while the return on the safe investment is 0. Banks differ in their ability to handle risk, which is represented by the parameter θ. The latter follows some distribution with the probability density function f (θ) on the interval [0, 1]. Banks with $\theta = 0$ are assumed to be bad at handling risk, while the opposite is the case for banks with $\theta = 1$. Intuitively, θ could represent the quality of portfolio management, such as degree of diversification, how much time or effort is invested in monitoring loans or general ability to assess risks, i.e. human factor. Since any bank is a financial intermediary, the money for investments must come from the bank's liabilities: in this model the choice is between equity (capital), k, and demand deposits, *(1-k)*. It may seem that such liability structure represents an oversimplification and the existence of other types of capital has been central in discussions of financial stability. However, for emerging market economies *"common equity has always been the major component of capital"* (IMF, 2012, p. 92), so it may not obscure reality so much after all. It is assumed that there are unlimited borrowing possibilities in the population, so a bank can borrow any amount of money and invest in productive alternatives.

On its liabilities each bank is obliged to pay some gross promised return. For simplicity only the gross promised return on equity is regarded as positive making equity a more expensive borrowing alternative. For illustration the bank's profit function could be written as $\pi(u, k)$, where u stands for the fraction of risky assets in the total assets. All banks are assumed to be of equal size with assets and liabilities summing up to 1, so u and k can thus be regarded both as fractions and as absolute amounts of risky investments and capital. The profit function is assumed to be increasing in the amount of risky investment, but decreasing in the amount of capital: $\pi'_u(u, k) > 0$ and $\pi'_k(u, k) < 0$. The latter assumption implies that the Modigliani-Miller theorem doesn't hold. The profit function is concave in u: $\pi''_{uu}(u, k) < 0$. Decreasing returns on u could be due to the fact that by issuing mortgages

continuously a bank would eventually have to go "down the list": issue loans to less and less responsible customers, which in turn affects the revenues. The effect of capital on profit is assumed to be linear, $\pi''_{kk}(u, k) = 0$, which will be justified below. Increasing capital is assumed to have no effect on the marginal profit from the risky investment: $\pi''_{uk}(u, k) = 0$.

It is assumed that there might exist some market discipline or "market capital requirements". As noted by, for instance, Berger, Herring and Szegö (1995) some factors, such as costs of financial distress, make creditors demand higher interest rates. *"In response, shareholders may choose to reduce these expected costs by increasing capital ratio of the bank"* (Berger et al., 1995, p. 6). A similar idea has been expressed by Piti Disyatat (2010, p. 716) who states that *"a bank can issue credit up to a certain multiple of its own capital, which is dictated either by regulation or by market discipline"*. The assumption about the existence of market capital requirements stands thus in contrast to a popular idea that *"depositors are not in a position to control the bank's activities (or to bargain with the owners)"* (Rochet, Freixas, 2008, p. 309). In line with this assumption the fraction of capital is assumed to be a weakly increasing and concave function of risky investments: $k'_u(u) \geq 0$ and $k''_{uu}(u) < 0$. The promised return on the capital and demand deposits is thus held fixed in the present model allowing the amount of capital to adjust. With "market capital requirements" the profit function may be formalized as $\pi(u, k(u))$.

Aggregate investment in risky assets is assumed to generate systemic risk with a potential cost for the economy in case of collapse, c(*X*), where *X* stands for the total sum of risky investments across all banks. It is assumed that the financial system can tolerate some certain level of *X* treated as a stochastic variable with a certain threshold, beyond which there is significant probability of an economic turmoil. Each bank takes the aggregate risk as given and is only able to estimate its individual probability of going bankrupt $y(u, k)$. The latter increases in the amount of risky alternative, $y'_u(u, k) > 0$, but decreases in the amount of capital, which acts as a *"buffer against unexpected losses"* (Hellwig 2010: 9), $y'_k(u, k) < 0$. Finally, it is assumed that the function of the individual probability of going bankrupt is convex in **u** and **k**: $y''_{uu}(u, k) > 0$ and $y''_{kk}(u, k) > 0$. The cross-derivative of this function is assumed to be negative: increasing capital with one more unit decreases the marginal probability of going bankrupt through one additional unit of investment in the risky asset: $y''_{uk}(u, k) < 0$. Each bank takes into consideration the possibility of facing systemic collapse

modeled as $y(u,k)c(X)$. With "market capital requirements" the function for the individual probability of going bankrupt becomes $y(u,k(u))$.

Both the profit function $\pi(u,k)$ and the individual probability of going bankrupt $y(u,k)$ are assumed to be functions of θ. Banks with better risk handling ability generate higher revenues from a given amount of risky investment: $\pi''_{u\theta}(u,k) > 0$. At the same time the marginal probability of going bankrupt decreases in θ, $y''_{u\theta}(u,k) < 0$, and the effect of an additional unit of capital has a stronger effect on the probability of going bankrupt for banks with high values of θ: $y''_{k\theta}(u,k) < 0$.

4.2 A simple illustration

The following model treats the financial system as an aggregation of banks making investment and funding decisions separately from each other and not being connected by the interbank market. The starting point of the model is the net present value (NPV) of a bank, which could be formalized the following way:

$$V(\theta) = \pi(u(\theta), k(u(\theta), \theta), \theta) - y(u(\theta), k(u(\theta), \theta), \theta)c(X)$$

The assumptions of the model could be illustrated graphically:

**Figure 1. Revenues from risky investments for different θ's.**
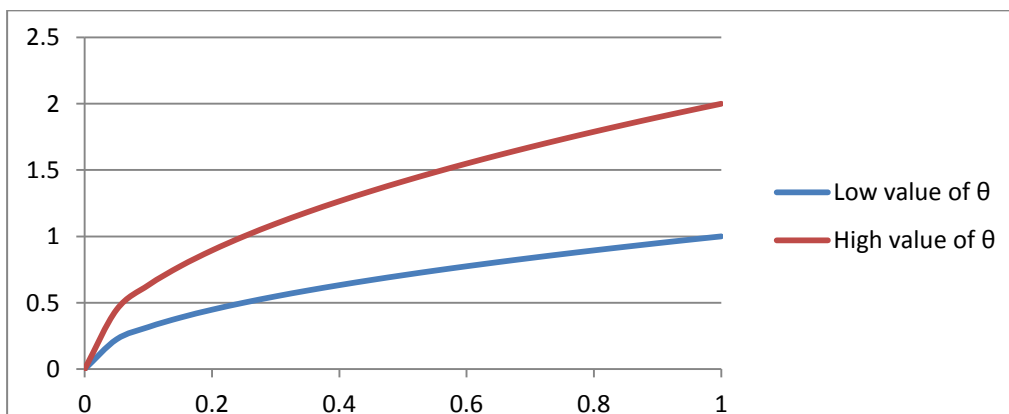
The fraction of risky investment, u, is depicted on the x-axis and a bank's revenues from u are depicted on the y-axis. Higher θ contributes to higher revenues for each level of u.

The effect of k on the profit function $\pi(u, k(u))$ stems from the assumption that the Modigliani-Miller theorem doesn't hold, which in turn implies that increasing capital fraction increases banks' total funding costs. Some empirical support of this can be found, for instance, in a paper by Bent Vale, who suggests that *"an increase in bank's equity ratio … will increase funding costs by an interval ranging from 11 bps to 41 bps"* (Vale, 2011, p. 13). However, this argument by itself doesn't imply the assumed linearity of the cost function. According to Vale, raising new capital may be associated with the "lemon problem": *"firms with the strongest incentive to issue new shares in the market are those firms, which are currently overvalued"* (ibid., p. 12). This will create difficulties with raising new equity and may, perhaps, suggest a convex cost of capital. At the same time *"when regulators require all banks to raise their equity ratio within a short horizon, issuing new equity in the market may not be a significant negative signal about the true value of the individual bank"* (ibid., p. 13). Since the present thesis focuses on financial regulation, the latter argument is adopted and the capital cost function is thus assumed to be linear: $\pi_{kk}''(u, k(u)) = 0$.

Figure 2. Individual probability of going bankrupt, $y(u, k)$, for different θ's.
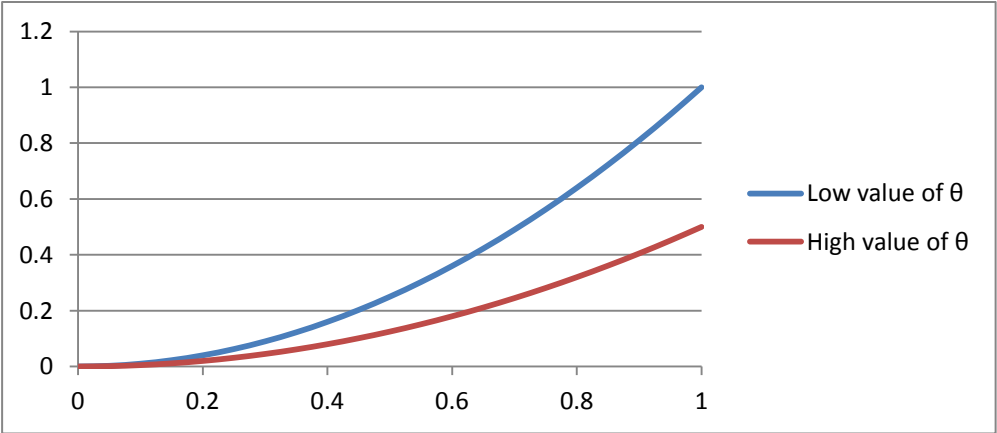
The fraction of risky investment, u, is depicted on the x-axis. Higher θ contributes to lower probability of going bankrupt for each level of u.

Figure 3. Individual probability of going bankrupt, $y(u, k)$, for different θ's.
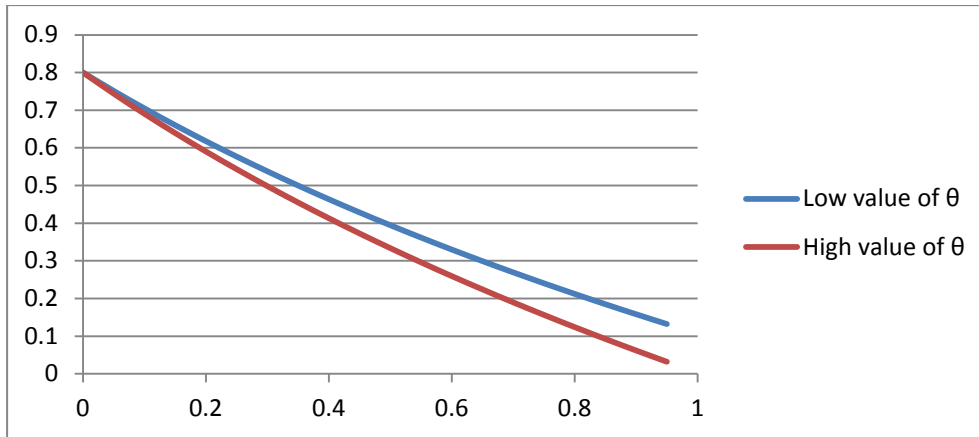
The fraction of capital, k, is depicted on the x-axis. Higher θ contributes to lower probability of going bankrupt for each level of k.

Assuming an interior solution and since the profit function is concave in u and the function of the individual probability of going bankrupt is convex in u, the NPV function will be concave and for a given θ have its maximum at:

$$\pi_u' + \pi_k' k_u' - (y_u' + y_k' k_u') c(X) = 0$$

This is a standard externality problem, which, in line with Perotti and Suarez (2011, p. 4), shows that *"even if an individual bank's funding decision takes into account its own exposure to refinancing risk, it will not internalize its systemwide effect"*. Since banks treat the aggregate cost of systemic collapse as given, they naturally opt for too much risky investment in their asset portfolios. The presence of market capital requirements both reduces the marginal cost and marginal profit and the total effect depends on the strength of the two. So the market may potentially partially correct the existing externality.

5   Regulation under perfect information

5.1 Regulation of assets

Suppose the social planner has perfect information about the distribution of θ among individual banks and can estimate the upper limit of aggregate risk that the financial system can tolerate, *X*, precisely. Since risky assets in the model represent mortgages, continuous lending leading to systemic risk accumulation beyond *X* would mean potential *"excessive rise in asset prices relative to fundamentals"* (Haugland, Vikøren, 2006, p. 25). Beyond this level many customers may start having difficulties repaying the mortgages and many banks may face unexpectedly high losses finding themselves on the verge of going bankrupt. A wave of defaults could path way for pecuniary externalities leading to price fall, which could generate further defaults. At the same time even if only some banks go bankrupt, this could have further effects through, for instance, the interbank market not modeled in the thesis. It has been observed that *"the rate of growth of bank lending to the private sector has, in the past, been a good predictor of financial crises"* (Goodhart et al., 2004, p. 600).

One obvious way to ensure stability in this situation is to introduce restrictions on **u**, the risk-generating illiquid asset, in order *"to limit the scope of the bank's ability to engage in moral-hazard behavior»* (Hellmann et al., 2000, p. 150).

This "isoperimetric problem" can be then formulated within the framework of control theory:

$$\max \int_0^1 [\pi(u(\theta), k(u(\theta), \theta), \theta) - y(u(\theta), k(u(\theta), \theta) \theta)c(X)]f(\theta)d\theta$$

$$\dot{x} = u(\theta)f(\theta), \ x(0) = 0, x(1) = X, u(\theta) = [0,1]$$

The Hamiltonian can be written as:

$$H(\theta, x, u, p) = \left[\pi\big(u, k(u)\big) - y(u, k(u))c(X)\right]f(\theta) + puf(\theta)$$

Under appropriate concavity and boundary assumptions and for each $\theta \in [0,1]$ an interior solution has to obey:

$$H'_u = \pi'_u + \pi'_k k'_u - (y'_u + y'_k k'_u)c(X) + p = 0 \quad and \quad H''_{uu} < 0$$

The function $p(\theta)$ satisfies the following equation:

$$\dot{p} = -H'_x$$
$$\dot{p} = 0$$

$p(\theta) = D$, constant, determined endogenously.

Since $p(\theta)$ measures the contribution to the value function that the social planner is maximizing if $x(\theta)$ was to increase with one more unit, it is reasonable to conjecture that $p(\theta) < 0$ in this case.

Note that from the first-order condition one can define $u = v(\theta, p, X)$, which can be inserted into the integral constraint to become:

$$X = \int_0^1 v(s, p, X) f(s) ds \quad => \quad p = p(X)$$

The condition for x is:

$$\dot{x} = u(\theta) f(\theta) \qquad \text{with } x(0) = 0, x(1) = X$$

The condition for u becomes:

$$H'_u = \pi'_u + \pi'_k k'_u - (y'_u + y'_k k'_u)c(X) + D = 0 \qquad \text{or}$$
$$\pi'_u - y'_k k'_u c(X) = y'_u c(X) - \pi'_k k'_u - D$$

The marginal benefit and marginal cost are equated. Unlike individual banks the social planner accounts for the cost of the systemic risk represented by D.

Looking at the optimality condition again:

$$H'_u = \pi'_u + \pi'_k k'_u - (y'_u + y'_k k'_u)c(X) + D = 0 \quad , \text{with } D < 0.$$

Differentiating the first order condition with respect to θ yields:

$$\pi''_{uu}\dot{u}(\theta) + \pi''_{uk}k'_u\dot{u}(\theta) + \pi''_{u\theta} + (\pi''_{ku}\dot{u}(\theta) + \pi''_{kk}k'_u\dot{u}(\theta) + \pi''_{k\theta})k'_u + k''_{uu}\dot{u}(\theta)\pi'_k -$$
$$(y''_{uu}\dot{u}(\theta) + y''_{uk}k'_u\dot{u}(\theta) + y''_{u\theta})c(X) - ((y''_{ku}\dot{u}(\theta) + y''_{kk}k'_u\dot{u}(\theta) + y''_{k\theta})k'_u +$$
$$k''_{uu}\dot{u}(\theta)y'_k)c(X) = 0$$

Collecting terms:

$$\pi''_{uu} + \pi''_{uk}k'_u + \pi''_{ku}k'_u + \pi''_{kk}(k'_u)^2 + \pi'_k k''_{uu} - c(X)(y''_{uu} + y''_{uk}k'_u + y''_{uk}k'_u + y''_{kk}(k'_u)^2 + y'_k k''_{uu})\dot{u}(\theta) = -\pi''_{u\theta} - \pi''_{k\theta}k'_u + y''_{u\theta}c(X) + y''_{k\theta}k'_u c(X)$$

Since $\pi''_{kk} = 0$, $\pi''_{k\theta} = 0$ and $\pi''_{uk} = 0$:

$$(\pi''_{uu} + \pi'_k k''_{uu} - c(X)(y''_{uu} + 2y''_{uk}k'_u + y''_{kk}(k'_u)^2 + y'_k k''_{uu}))\dot{u}(\theta) = -\pi''_{u\theta} + y''_{u\theta}c(X) + y''_{k\theta}k'_u c(X)$$

The right-hand side of the expression is always negative given the assumptions above. On the left-hand side all the terms have a negative sign, except for $2y''_{uk}k'_u$ and $\pi'_k k''_{uu}$. If k is weakly increasing in u, $k'_u(u) \geq 0$, then both k_u and k_{uu} are likely to be small. In addition to that, the cross effect, y''_{uk}, may be assumed to be weaker than the direct effects of y''_{uu} and y''_{kk}. This suggests that the amount of risky investment, u, must be an increasing function of θ.

Figure 4. A possible illustration of the optimal path for $u(\theta)$.
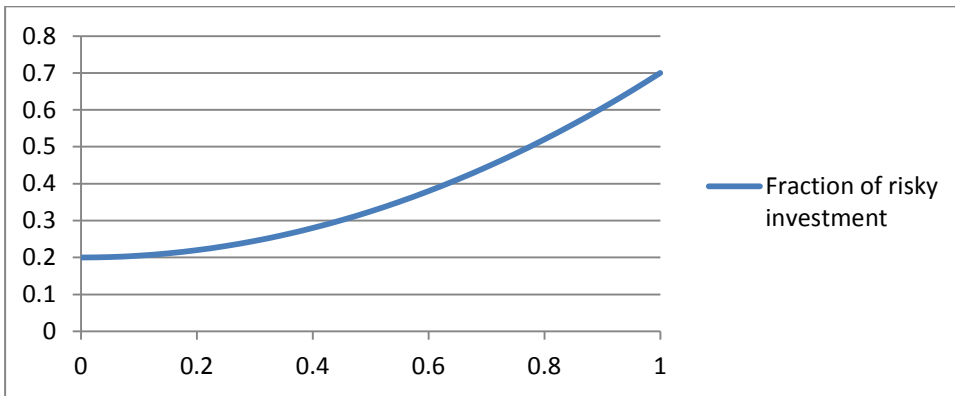
θ is depicted on the x-axis. The authorities can control this path by changing the terminal condition for x, $x(1) = X$.

The illustration above shows that the social planner will allow banks with better risk handling ability to invest more in the risky asset. However, since the social planner accounts for the aggregate risk, it is reasonable to imply that banks will be restricted in their investment decisions compared to the unregulated equilibrium. Given that "market capital requirements" decrease the optimal amount of risky investments, their strength will determine how much the assets will have to be restricted compared to the unregulated equilibrium in order to secure

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financial stability. Since $k'_u(u) \geq 0$, banks with high θ and high u will also need to hold either the same or a larger fraction of capital as a result of market discipline. This suggests that $k(u)$ will be a weakly increasing function of θ.

Suppose now that X is changed, set at a lower level X'. Then, since the aggregate risk is defined as $= \int_0^a u(\tau)f(\tau)d\tau$, the amount of u must decrease. So if X is lowered, then the path for $u(\theta)$ will also be lowered on the graph, but will still remain increasing, because different banks' credit ability and the distribution of θ remain unchanged. Under perfect information, if X is set at a lower level, banks with low values of θ will not be allowed to operate. Graphically this implies the following shift:

Figure 5. The effect of lowering the allowed level of aggregate risk.
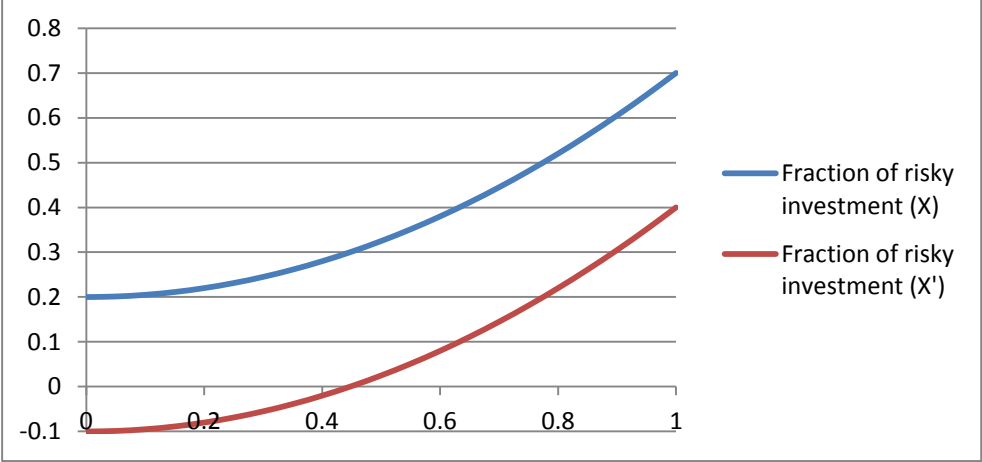
θ is depicted on the x-axis. û(θ) summing up to X' is still an increasing function of θ.

As noted above the "liquidity coverage ratio" from Basel III *"requires banks to back their use of short-term funding with the holding of high-quality liquid assets"* (Perotti, Suarez, 2011, p. 25). Since the asset side consists of just two alternatives in this model, imposing a prescription on the amount of investment in the risky asset for each bank of type θ is the same as imposing a prescription on the amount of investment in the safe alternative. So the path for u found above could just as well be regarded as a liquidity requirement. If banks' risk handling is perfect information, banks that are bad at risk handling would need to hold more liquidity reserves *"that could be easily sold, presumably at no fire-sale loss, in case of a crisis"* (ibid.) in order to create trust and attract customers.

At the same time regulation of the asset side insures against liquidity but not credit risk. Illiquid assets can give unexpectedly low returns for each individual bank and losses would need to be covered with capital. Without any regulation of liabilities capital adjusts only through "market capital requirements" expressed by $k'_u(u) > 0$. If $k'_u(u) = 0$, the market has virtually no power on the banks. Without "market capital requirements" banks might still avoid investing everything in the risky alternative, because capital actually reduces the individual probability of going bankrupt. Without market power the adjustment equation becomes:

$$\pi'_u(u,k) = y'_u c(X) - D, \quad D < 0$$

Differentiating the expression with respect to θ yields:

$$\pi''_{uu}\dot{u}(\theta) + \pi''_{u\theta} - (y''_{uu}\dot{u}(\theta) + y''_{u\theta})c(X) = 0 \qquad \text{or}$$
$$(\pi''_{uu} - c(X)y''_{uu})\dot{u}(\theta) = -\pi''_{u\theta} + y''_{u\theta}c(X)$$

It is now even more obvious that **u** is an increasing function of θ. The optimal capital fraction **k** for a given θ will be given by:

$$\max V(\theta) = (\pi(u(\theta),k,\theta) - y(u(\theta),k,\theta)c(X)$$
$$\pi'_k = y'_k c(X)$$

Given the assumptions about the two functions, it is clear that if a marginal reduction in the expected cost of system collapse is less than a marginal reduction in the bank's profit from increasing capital, the bank will have an incentive to reduce its capital. Since $y''_{k\theta} < 0$, banks that are bad at risk handling will have the biggest incentive of this kind. The individual probability of default, $y(u,k)$, could thus correspond to Internal Ratings-Based Approach used to assess credit risks. Without market discipline the amount of capital would be connected to the banks' subjective estimates of the probability of going bankrupt. The high cost of capital might create an incentive to underestimate this probability, but even if it is estimated correctly, capital ratios will still not be connected to the amount of risky assets. So capital buffers can be optimal only by chance and might not be able to cover banks' losses in cases of idiosyncratic shocks.

5.2 Regulation of liabilities

Suppose the social planner considers "market capital requirements" to be insufficient and wants to ensure stability of the system by regulating banks' liabilities. One idea could be to tie the amount of capital to the bank's overall assets. Since in this model k stands for the fraction of capital in the total liabilities and both assets and liabilities are equal to 1, this type of regulation could be modeled by simply making k exogenous in the optimization problem. Assuming that the social planner knows the level, at which k should be fixed, insufficiency of "market capital requirements" will result in an increase of capital buffers.

The social planner will then maximize:

$$\max \int_0^1 [\pi(u(\theta), k', \theta) - y(u(\theta), k')c(X)]f(\theta)d\theta$$
$$\dot{x} = u(\theta)f(\theta), \ x(0) = 0, \ x(1) = X, \ u(\theta) \in [0,1]$$

The Hamiltonian can be written as:

$$H(\theta, x, u, p) = [\pi(u, k') - y(u, k')c(X)]f(\theta) + puf(\theta)$$

The condition for u is then:

$$H_u' = \pi_u'(u, k') - y_u'(u, k')c(X) + p = 0$$

The function $p(\theta)$ satisfies the following equation:

$$\dot{p} = -H_x'$$
$$\dot{p} = 0$$
$$p(\theta) = D \text{ , constant.}$$

Since $p(\theta)$ measures the contribution to the value function that the social planner is maximizing if $x(\theta)$ was to increase with one more unit, it is reasonable to conjecture that $p(\theta)$ is negative in this case.

In the first-order condition, due to assumptions about cross-derivatives of the two functions, $\pi_u'(u, k')$ will be unchanged, while $y_u'(u, k')$ will now be lower than in the case with "market capital requirements". For given θ an increase in u is needed to equate both sides of the

expression. Regulating liabilities in this manner seems to create *"incentives for banks to allocate resources to higher-risk assets because the returns on those assets were not offset by a requirement to hold larger amounts of capital against them"* (IMF, 2012, p. 116-117). However, since aggregate risk X is determined solely by accumulation of risky assets, $\dot{x} = u(\theta)f(\theta)$, an increase in **u** will not be allowed by the social planner, because the system will otherwise end up with the amount of aggregate risk higher than X. This suggests that the path for **u** should be left unchanged.

In order to deal with the incentive to invest more into risky assets the social planner may conclude that *"the key determinant of the size of the required capital buffer should be the riskiness of the bank's assets"* (Morris, Shin, 2008, p. 230). Assuming that the previously described regulation on assets is in place, risk-weighted capital requirements could be modeled as:

$$\frac{k}{u} = \alpha \text{ or } k \geq \alpha u$$

Assuming that $\alpha(\theta)$ is a control variable as well, the new maximization problem becomes:
$$H(\theta, x, u, p) = [\pi(u, \alpha u) - y(u, \alpha u)c(X)]f(\theta) + puf(\theta)$$

The solution for **u** is then:

$$H'_u = \pi'_u + \alpha\pi'_k - (y'_u + \alpha y'_k)c(X) + D = 0$$
$$\pi'_u - y'_u c(X) + \alpha(\pi'_k - y'_k c(X)) + D = 0 \text{, where D} < 0 \text{ as previously.}$$

$$H'_\alpha = (\pi'_k u - c(X)y'_k u)f(\theta) = 0 \text{, which implies}$$

$$\pi'_k - c(X)y'_k = 0 \quad \text{for } u > 0$$

Inserting the latter result into the first equation gives:

$$\pi'_u - c(X)y'_u + D = 0$$

Differentiating the two conditions with respect to θ:

$$\pi''_{ku}\dot{u}(\theta) + \pi''_{kk}\left(u\dot{\alpha}(\theta) + \alpha\dot{u}(\theta)\right) + \pi''_{k\theta} - (y''_{ku}\dot{u}(\theta) + y''_{kk}\left(u\dot{\alpha}(\theta) + \alpha\dot{u}(\theta)\right) + y''_{k\theta})c(X) = 0$$

$\pi''_{uu}\dot{u}(\theta) + \pi''_{uk}\big(u\dot{\alpha}(\theta) + \alpha\dot{u}(\theta)\big) + \pi''_{u\theta} - \big(y''_{uu}\dot{u}(\theta) + y''_{uk}\big(u\dot{\alpha}(\theta) + \alpha\dot{u}(\theta)\big) + y''_{u\theta}\big)c(X) = 0$

Collecting terms:

$\big(\pi''_{ku} + \pi''_{kk}\alpha - y''_{ku}c(X) - y''_{kk}\alpha c(X)\big)\dot{u}(\theta) + (\pi''_{kk} - y''_{kk}c(X))u\dot{\alpha}(\theta) = -\pi''_{k\theta} + y''_{k\theta}c(X)$

$\big(\pi''_{uu} + \pi''_{uk}\alpha - y''_{uu}c(X) - y''_{uk}\alpha c(X)\big)\dot{u}(\theta) + (\pi''_{uk} - y''_{uk}c(X))u\dot{\alpha}(\theta) = -\pi''_{u\theta} + y''_{u\theta}c(X)$

Using the fact that $\pi''_{kk} = 0$, $\pi''_{k\theta} = 0$ and $\pi''_{ku} = 0$ the first expression becomes $\big(-y''_{ku}c(X) - y''_{kk}\alpha c(X)\big)\dot{u}(\theta) = y''_{kk}c(X)u\dot{\alpha}(\theta) + y''_{k\theta}c(X)$ or

$\dot{u}(\theta) = \dfrac{y''_{kk}c(X)u\dot{\alpha}(\theta) + y''_{k\theta}c(X)}{-y''_{ku}c(X) - y''_{kk}\alpha c(X)} = \dfrac{y''_{kk}c(X)u}{-y''_{ku}c(X) - y''_{kk}\alpha c(X)}\dot{\alpha}(\theta) + \dfrac{y''_{k\theta}c(X)}{-y''_{ku}c(X) - y''_{kk}\alpha c(X)}$

Inserting the expression for $\dot{u}(\theta)$ into the second expression:

$\big(\pi''_{uu} - y''_{uu}c(X) - y''_{uk}\alpha c(X)\big)\Big(\dfrac{y''_{kk}c(X)u}{-y''_{ku}c(X) - y''_{kk}\alpha c(X)}\dot{\alpha}(\theta) + \dfrac{y''_{k\theta}c(X)}{-y''_{ku}c(X) - y''_{kk}\alpha c(X)}\Big) - y_{uk}''c(X)u\dot{\alpha}(\theta) = -\pi''_{u\theta} + y''_{u\theta}c(X)$

Collecting terms:

$\dfrac{y''_{kk}c(X)(\pi''_{uu} - y''_{uu}c(X) - y''_{uk}\alpha c(X))u}{-y''_{ku}c(X) - y''_{kk}\alpha c(X)}\dot{\alpha}(\theta) + \dfrac{y''_{k\theta}c(X)(\pi''_{uu} - y''_{uu}c(X) - y''_{uk}\alpha c(X))}{-y_{ku}c(X) - y_{kk}\alpha c(X)} - y''_{uk}c(X)u\dot{\alpha}(\theta) = -\pi''_{u\theta} + y''_{u\theta}c(X)$

The final result is thus:

$\Big(\dfrac{y''_{kk}\big(\pi''_{uu} - y''_{uu}c(X) - y''_{uk}\alpha c(X)\big)}{-y_{ku} - y_{kk}\alpha} - y''_{uk}c(X)\Big)u\dot{\alpha}(\theta) =$

$-\pi''_{u\theta} + y''_{u\theta}c(X) - \dfrac{y''_{k\theta}(\pi''_{uu} - y''_{uu}c(X) - y''_{uk}\alpha c(X))}{-y_{ku} - y_{kk}\alpha}$

The signs of the left-hand side and the right-hand side are ambiguous. In order to arrive to formal conclusions, it will be assumed that the effect of the cross-derivative, y''_{uk}, is weaker than the direct effects, y''_{uu} and y''_{kk}.

For simplicity y''_{uk} is set at 0:

$$\frac{y''_{kk}\left(\pi''_{uu}-y''_{uu}c(X)\right)}{-y''_{kk}\alpha}u\dot{\alpha}(\theta) = -\pi''_{u\theta} + y''_{u\theta}c(X) - \frac{y''_{k\theta}(\pi''_{uu}-y''_{uu}c(X))}{-y''_{kk}\alpha}$$

From this expression it is clear that the left-hand side of the equation is positive, while the right-hand side is ambiguous. If θ is characterized by sufficient variation in profit functions and probabilities of going bankrupt, so that the effect of $(-\pi''_{u\theta} + y''_{u\theta}c(X))$ dominates, then optimal α will be a decreasing function of θ. In other words, if a marginal increase in θ increases the revenues from **u** and/or decreases the probability of going bankrupt from investing in **u** sufficiently much, then optimal capital requirements will be decreasing in θ. On the other hand, if the effect of risky investment on the profit function and the individual probability of going bankrupt do not differ much across banks, flat or even increasing capital requirements could be optimal. In the following sufficient variation in θ with respect to profit functions and probabilities of going bankrupt is assumed. Intuitively, banks that are good at handling risk do not need the same amount of such type of buffer for the risky investments as do banks that are bad at handling risk. This is in line with the general idea in the theoretical literature on capital regulation stressing that *"required equity is greatest for the riskiest borrowers"* (Coulter et al., 2013, p. 6). However, since α was originally defined as the ratio of capital to risky investment, the fact that $\dot{\alpha}(\theta) < 0$ doesn't imply anything about the absolute amount of capital for different banks: the latter could still be growing in θ together with the amount of risky investments.

Figure 6. The optimal path of risk-weighted capital requirements $\boldsymbol{\alpha(\theta)}$.
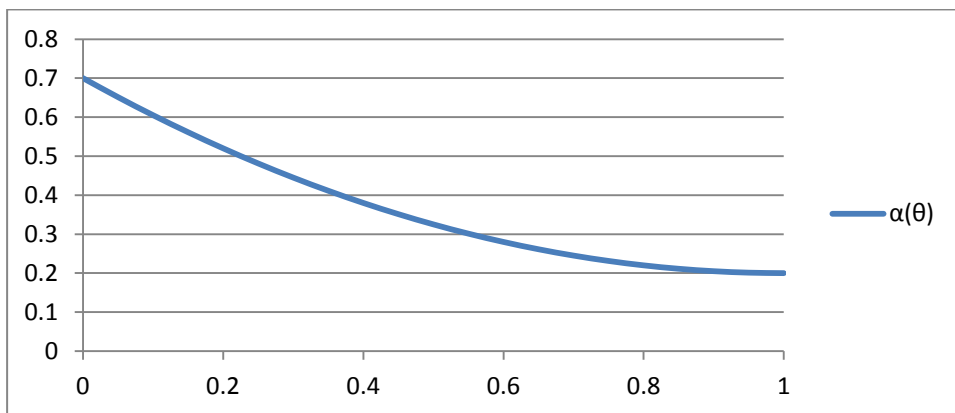
θ is drawn on the x-axis.

Returning back to the condition for $\dot{u}(\theta)$:

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$$\dot{u}(\theta) = \frac{y''_{kk}c(X)u\dot{\alpha}(\theta) + y''_{k\theta}c(X)}{-y_{ku}c(X)-y_{kk}\alpha c(X)} = \frac{y''_{kk}c(X)u}{-y''_{ku}c(X)-y''_{kk}\alpha c(X)}\dot{\alpha}(\theta) + \frac{y''_{k\theta}c(X)}{-y''_{ku}c(X)-y''_{kk}\alpha c(X)}$$

Since $\dot{\alpha}(\theta) < 0$, it is clear that $\dot{u}(\theta)$ will once again be an increasing function of θ given the assumption about the weak effect of the cross-derivative y''_{ku} .

6 Regulation under asymmetric information

The mechanisms illustrated above suggest a too rosy picture of the task faced by regulators. In a more realistic setting potential social planner would face several serious challenges. First of all, there is an estimation problem. In order to effectively regulate the asset side, the planner must know the amount of risk the system as a whole can tolerate represented by *X*, since this information is used to distribute risky assets among different types of banks. In reality authorities can only make estimates of the aggregate risk on the basis of growth rates of various assets and other financial indicators. In a recent report by Brunnermeier et al. (2009, p. 30) it is suggested that *"financial authorities should be alerted when clear indicators of a bubble emerge, even if the bubble cannot be identified for certain"*. Secondly, such parameters as the ability to handle risk θ, the impact of risky assets and capital on the profit function, $\pi_u'(u, k)$ and $\pi_k'(u, k)$, and the impact of risky assets and capital on the individual probability of bankruptcy, $y_u'(u, k)$ and $y_k'(u, k)$, are typically *reported* by banks themselves. If regulation is to be efficient, banks must then have an incentive to report such parameters truthfully. This represents a problem of private information.

In order to illustrate banks' incentives, consider the regulation pattern outlined above. It was suggested that ***u*** must be following an increasing path and capital must either be tied to the risky or overall assets. If the latter is the case, then the fraction of capital is fixed, and since all banks are of equal size in the model, the absolute amount of capital kept as a buffer is the same for all types θ. In this situation banks with high values of θ, being allowed to invest more in risky assets than banks with low values of θ, will generate higher revenues. The cost of capital will be the same for all banks. This suggests that banks with high values of θ will generate higher profits. Since the probability of going bankrupt, $y(u, k)$, is increasing and convex in ***u*** and decreasing and convex in ***k***, banks with low investments in ***u*** will face only a small marginal increase in $y(u, k)$ if they increase risky investments. This creates an incentive for banks with low values of θ to pretend that they are better at risk handling than they are in reality if information about true θ is private.

The second case is a bit more challenging. If the regulator chooses to assign an increasing path for ***u*** and tie capital to risky assets, then the optimal ratio of capital to risky

assets is decreasing in θ, $\dot{\alpha}(\theta) < 0$. Here a potential ambiguity arises, since banks with high values of θ have lower α, but larger investments in risky assets, so it is uncertain if they actually have more capital in absolute value compared to banks with low values of θ. Suppose that decreasing α means that banks with high values of θ hold less capital in absolute value than banks with low values of θ. Then by mimicking higher θ than what is the case in reality banks with low values of θ will face a possibility of increasing $\boldsymbol{u}$ and decreasing $\boldsymbol{k}$. If they have relatively low investments in $\boldsymbol{u}$ and high capital buffers $\boldsymbol{k}$ to begin with, then marginal increase in $\boldsymbol{u}$ and decrease in $\boldsymbol{k}$ will produce a large positive effect on the NPV due to concavity of the profit function and a small negative effect on the individual probability of going bankrupt due to convexity of $y(u, k)$ in both variables. This will create an incentive for banks with low values of θ to pretend they are better at risk handling. Suppose that decreasing α means that banks with high values of θ hold the same amount capital in absolute value as banks with low values of θ. Again, this suggests that banks with low values of θ will have incentives to pretend they are better at risk handling than they actually are. Finally, if decreasing α means that banks with high values of θ hold more capital in absolute value than banks with low values of θ, then different scenarios are possible, and the conclusions will depend on the assumptions about the profit function, capital costs and effects of θ on the two functions. What is important, however, is that as long some banks receive larger profits, other banks would like to mimic them.

Suppose the social planner wants to find an optimal combination of the regulation mechanisms outlined above given informational asymmetry. Once again the NPV function of a single bank is given by:

$$V(\theta) = \pi(u(\theta), k, \theta) - y(u(\theta), k), \theta)c(X)$$

If the social planner chooses to fix $\boldsymbol{k}$, then, as mentioned above, banks with low values of θ and low prescribed investments in $\boldsymbol{u}$ may be willing to mimic banks with higher values of θ**.** This effect will actually be reinforced if $y_u'(u, k)$ is underestimated through IRBA-modeling. Banks with high values of θ will also face an incentive to increase $\boldsymbol{u}$ due to concavity of the profit function and fixed cost of capital, but at the same time may experience a larger increase in the individual probability of going bankrupt. The situation for such banks is thus ambiguous. If banks with high values of θ do not change their investment strategy and since the aggregation of risky assets generates systemic risk in the model, the level of X is likely to

surpass the critical threshold. The social planner would then need to allow for less steep or even flat path of u, allowing banks with different values of θ to invest more or less the same in u. This will naturally result in ineffective risk-sharing: banks with high values of θ will have too big capital buffers as a proportion of risky assets or, alternatively, banks with low values of θ will have too small capital buffers. If k is set high enough, then banks with low values of θ may still have capital buffers that will prevent them from going bankrupt in a situation of crisis, but banks with high values of θ will end up with too much capital and suboptimal amount of risky investment. Moreover, since banks with low values of θ invest more in the risky assets than what is prescribed by the social planner, such banks will also end up with suboptimal liquidity buffers. If a large enough aggregate shock occurs, the system will need to rely on the interbank market or some sort of Lender of Last Resort, the Central Bank.

Alternatively, if the social planner chooses to combine regulation of assets with risk-weighted capital requirements under asymmetric information, different scenarios are possible. The crucial assumption here is what $\dot{\alpha}(\theta) < 0$ means for the absolute amount of capital. Recall that $k/u = \alpha$, and $\dot{u}(\theta) > 0$. Decreasing α is thus compatible with decreasing, unchanged and increasing k. However, as pointed out previously, both decreasing and unchanged k lead to a situation where it may become attractive for less capable banks to mimic banks that are better at risk-handling, which will consequently pose a threat to financial stability. Consider therefore the case where the social planner imposes $\dot{\alpha}(\theta) < 0$ as a capital requirement, which still means that k is growing in α. The cost of capital is linear, while the profit function is concave in u. This generates an ambiguous situation. For simplicity an illustration of what better risk handling implies for the profit function is provided.

Figure 7. The effect of higher θ on optimal choice of the amount of risky investment.
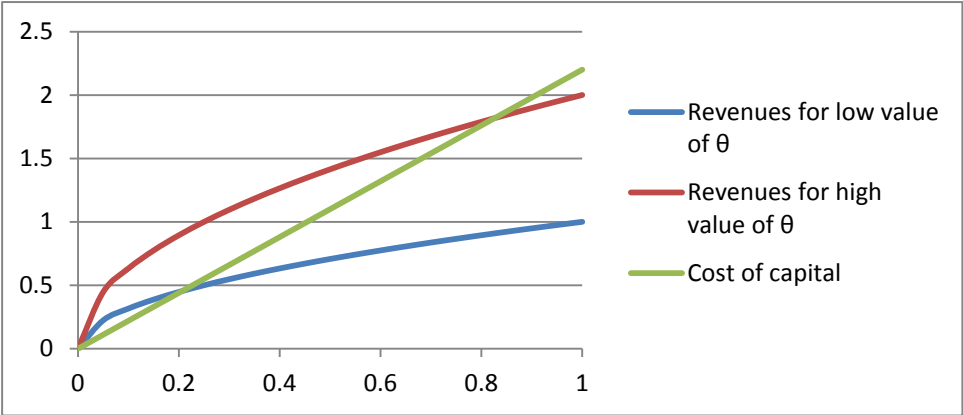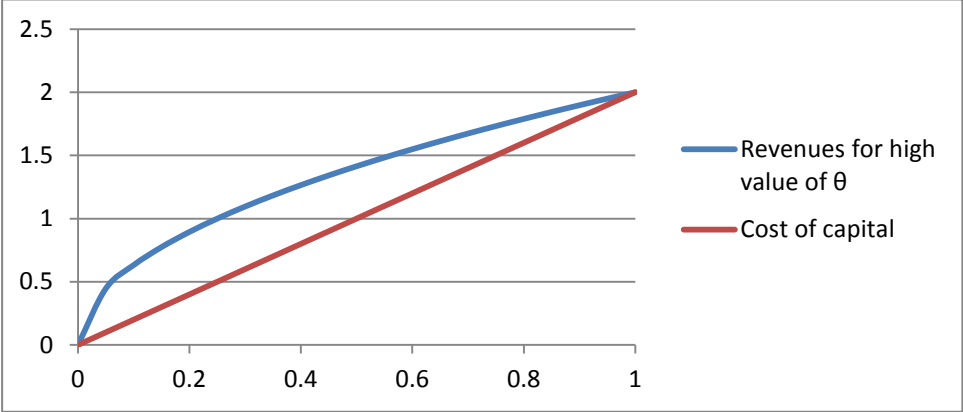

The fraction of risky investments, **u**, is depicted on the x-axis, while revenues from **u** and the cost of capital **k** are on the y-axis.

Profit considerations may deter banks with low values of θ from mimicking those with higher values of θ**,** simply because increasing risky investment given their risk handling may produce suboptimal or even negative NPV. This is because the cost of capital grows faster than the revenues from **u**. Since the individual probability of going bankrupt is increasing and convex in **u** and decreasing and convex in **k**, increasing both capital and the fraction of risky investments will at some point add negatively to the NPV. Banks will prefer the level of **u** corresponding to the biggest wedge between the revenues from **u** and the cost of capital **k** corresponding to maximum profit. However, if a bank with low value of θ is only allowed to make a small investment in **u** that it itself regards as suboptimal, then such bank will have an incentive to mimic banks with better risk handling both because marginal profit would exceed marginal cost of capital and because with very low investment in **u** increasing both risky investments and capital *decreases* the individual probability of going bankrupt. In other words, for low levels of investment in **u**, increasing both **u** and **k** is likely to contribute positively to the NPV through the individual probability of going bankrupt. The question is then, which level of **u** the bank will regard as optimal. Obviously, it must be the amount of investment corresponding to the unregulated equilibrium. As it has been pointed out before, regulation of assets entails lower investments in risky assets than under unregulated equilibrium especially for banks with low values of θ.

In order to secure an increasing path of risky investments and decreasing path of capital requirements, the social planner should opt for a high value of *α* for banks that are bad at risk handling and for a low value of *α* for banks that are good at risk handling. A high value

of α implies that cost of capital must be growing fast if u increases and the opposite is the case for a low value of α. Graphically this can be illustrated the following way:

Figure 8. Capital requirements for banks that are good at risk handling (low α).

The fraction of risky investment, u, is depicted on the x-axis and the revenues from u and the cost of capital k are depicted on the y-axis.

Figure 9. Capital requirements for banks that are bad at handling risk (high α).
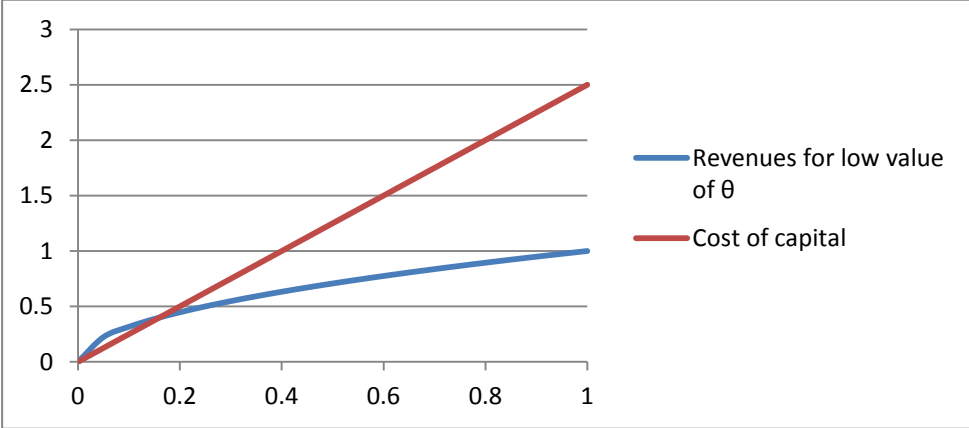
The fraction of risky investment, u, is depicted on the x-axis and the revenues from u and the cost of capital k are depicted on the y-axis. The revenues from u for banks that are bad at risk handling are more concave in u.

However, imposing decreasing α will mean that the capital cost function is going to be steeper for banks with low values of θ. Banks that are bad at risk handling will then have an incentive to mimic banks that are good at risk handling. This can be illustrated with the following graph:

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Figure 10. The effect of decreasing α on optimal adjustment of the amount of risky investment.

The fraction of risky investment, u, is depicted on the x-axis, while both revenues from u and cost of capital are depicted on the y-axis.
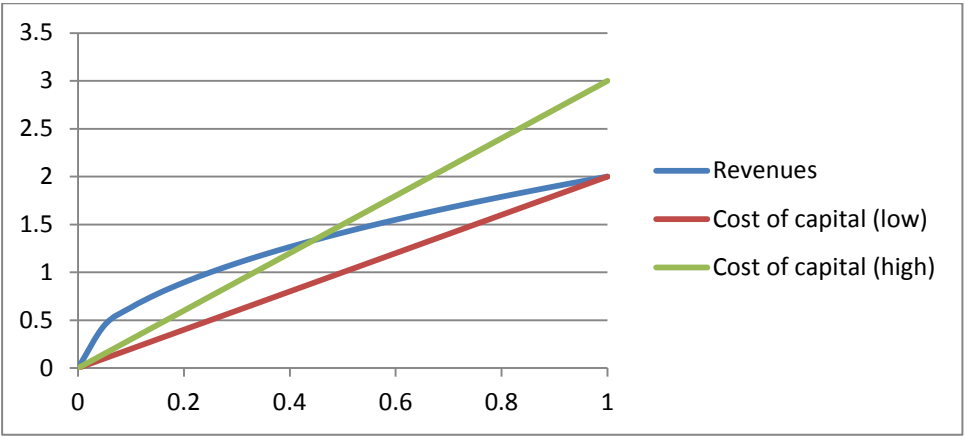
For given concavity of revenues, slacker capital cost function will correspond to a higher optimal level of u. So there will be stronger incentives for banks with low values of θ to mimic banks with higher values of θ. It should be noted that increasing both u and k for low initial values of both *reduces* the marginal probability of going bankrupt and contributes positively to the NPV. By mimicking better risk handling a bank with some low value of θ will then be able to increase its investment in risky assets and hold a smaller capital buffer as a fraction of those assets.

The social planner can of course regulate the slope of the cost function by choosing a higher ratio for $\frac{k}{u}$ and may thus consider imposing same α for all banks. This would ensure that k grows proportionally with u in θ, which would imply a faster growing k compared with the previous solution. Here, however, a new challenge arises, since it is assumed that the first-best α must be a decreasing function of θ. Keeping α constant means that either banks with high values of θ will end up with a higher than optimal level of k or banks with low values of θ will end up with a lower than optimal level of k or both. Graphically this implies:

**Figure 11. Alternative possibilities of setting capital requirements α.**
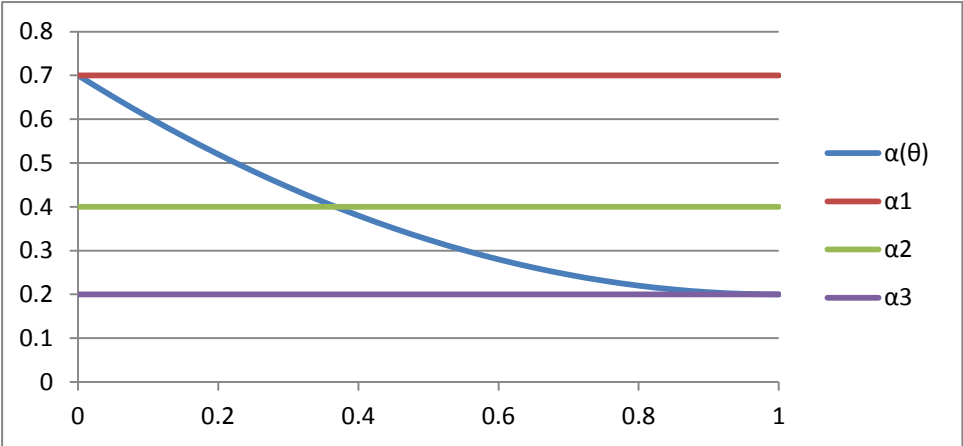
Θ is depicted on the x-axis. The optimal $\alpha(\theta)$ found under perfect information is a decreasing function of θ.

Choosing α at the same level for all banks means that it must be set either at the level of banks that are good at risk handling, at the level of banks that are bad at risk handling or at some intermediate level. Suppose the social planner sets α at the level, which is optimal for banks with high values of θ. This will once again imply a slack capital cost function. This is likely to produce incentives to mimic banks with better ability for risk-handling and invest more in u. This will result in both liquidity risk, since liquidity buffers will decrease, and credit risk. Obviously, the same will hold for the intermediate case as well.

Setting α at the level, which is optimal for banks with low values of θ, will make banks with high values of θ "*hold an inefficiently high amount of capital*" (Hellmann et al., 2000, p. 148). Since the profit function is concave in u and the cost of capital is linear, this will most likely produce suboptimal profits for the banks with high values of θ and in addition may add to their perceived risk of going bankrupt, since $y(u, k)$ is increasing and convex in u and decreasing and convex in k. Banks with low values of θ will now have weaker incentives to mimic those with high values of θ, because increasing investments in u will produce an increase in revenue that is less than increase in cost. However, banks with high values of θ may acquire an incentive to reduce their investments in u in order to decrease the linear cost of capital and the probability of going bankrupt. This will not threaten financial stability, since the latter is directly connected to the aggregate investment in u, but will decrease the aggregate investment in risky assets. This may be illustrated with the graph used above:

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Figure 12. The effect of stricter capital requirements on optimal adjustment of the amount of risky investment.
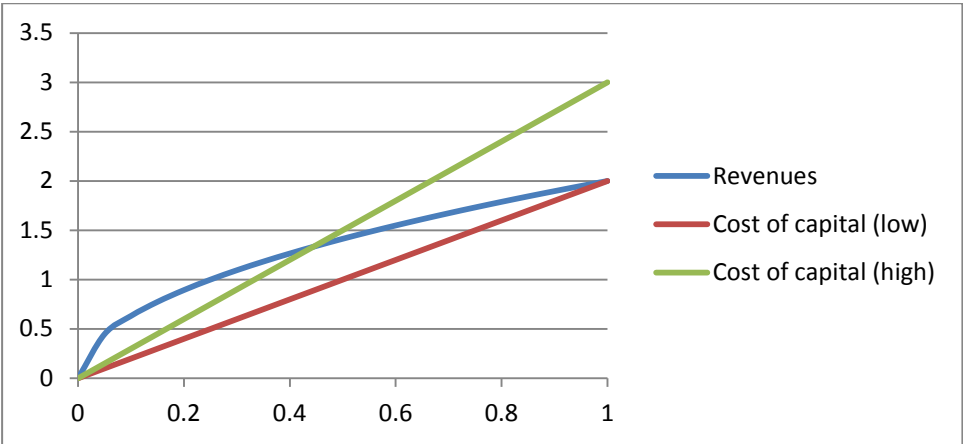
The amount of risky investment, **u**, is depicted on the x-axis and the revenues from **u** and the cost of capital **k** are depicted on the y-axis.

Given the ability to handle risk and the slope of capital cost, the banks will adjust in order to maximize their profits, which will lead to reduction in investment in **u** for banks with higher values of θ. Since **u** was initially distributed in such a way that the overall investment in **u** summed up to the maximum amount of risk the system can tolerate, X, decrease in **u** would lead to a decrease in the aggregate risk X. At the same time since the individual probability of going bankrupt $y(u, k)$ is convex in **u** and **k**, banks with high values of θ will have the strongest incentive of all banks to decrease their investments in **u**, since they have the largest fractions of risky investments and capital among banks and that is likely to contribute negatively to their NPV through $y(u, k)$.

Thus, if the social planner wants to insure against credit risk, (s)he should set α at the level, which is optimal for the banks with lowest values of θ. If, however, the main goal is to make the aggregate risk be equal to X, (s)he should opt for some intermediate solution: setting capital requirements, α, at a level that is somewhat below what is optimal for banks with the lowest values of θ. In that situation the worst banks will invest somewhat more in **u** than what is optimal for them, the best banks will invest somewhat less and the aggregate risk will sum up to X.

It is possible to find the optimal constant α mathematically. Suppose α is now treated as constant in the optimization problem:

$$H(\theta, x, u, p) = [\pi(u, \alpha u) - y(u, \alpha u)c(X)]f(\theta) + puf(\theta)$$

For each $\theta \in [0,1]$ the solution for **u** is then:

$$H'_u = \pi'_u + \alpha\pi'_k - (y'_u + \alpha y'_k)c(X) + D = 0$$
$$\pi'_u - y'_u c(X) + \alpha(\pi'_k - y'_k c(X)) + D = 0 \text{ , where D} < 0 \text{ as previously.}$$

From the first-order condition for **u**, we can define $u = v(\theta, \alpha, D, X)$, which can be inserted into the integral constraint to become:

$$X = \int_0^1 v(s, D, \alpha, X)f(s)ds \Rightarrow \quad p = D(\alpha, X)$$

Suppose that both α and X can be chosen by the regulator. Let then $W(\alpha, X)$ be the value function of the problem above that was solved for fixed α and X. For α and X to be optimal we have $W'(\alpha) = 0$, $W''(\alpha) < 0$ and $W'(X) = 0$, $W''(X) < 0$. Suppose that D is independent of type:

$$W'(X) = \int_0^1 \left[(\pi'_u + \alpha\pi'_k - y'_u c(X) - \alpha y'_k c(X))u'_X - y(u, \alpha u)c'(X)\right]f(\theta)d\theta =$$
$$= \int_0^1 [-D - y(u, \alpha u)c'(X)]f(\theta)d\theta = 0$$
$$D = -\int_0^1 [y(u, \alpha u)c'(X)]f(\theta)d\theta$$
$$D = -c'(X)\int_0^1 [y(u, \alpha u)]f(\theta)d\theta < 0$$

This demonstrates that overall investment in **u** will be lower if regulated by the social planner compared to the market equilibrium. Moreover, the result above defines the optimal level of X.

$$W'(\alpha) = \int_0^1 \left[(\pi'_u + \alpha\pi'_k - y'_u c(X) - \alpha y'_k c(X))u'_\alpha + \pi'_k u - uy'_k c(X)\right]f(\theta)d\theta =$$
$$= \int_0^1 [-D + \pi'_k u - uy'_k c(X)]f(\theta)d\theta = 0$$
$$D = \int_0^1 [u(\pi'_k - y'_k c(X))]f(\theta)d\theta \qquad \qquad .$$

Similarly, the result above defines an optimal α. Since the value function depends both on α and X, optimality in this case suggests that there should be cost efficiency: the two marginal costs above should be equal.

Finally, it might be interesting to consider what may happen if the social planner decides to lower the level of *X* under asymmetric information. As mentioned before, this will imply the following shift:

Figure 13. The effect of lowering the allowed level of aggregate risk.
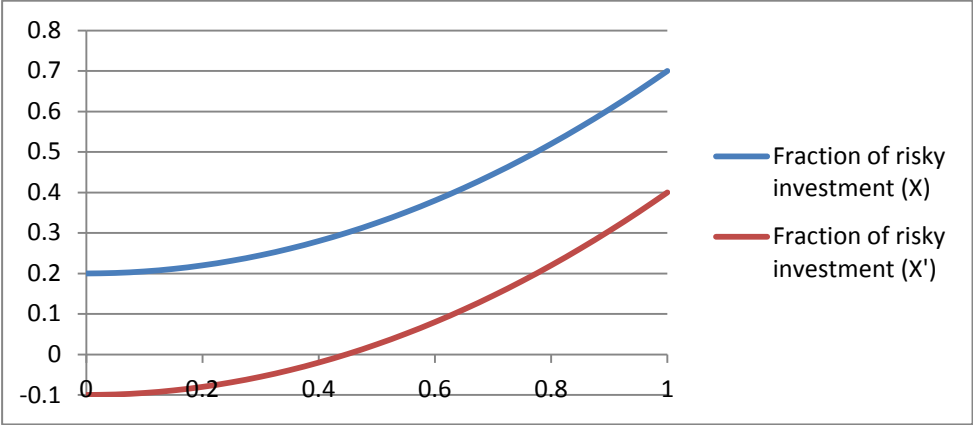
θ is depicted on the x-axis. $\hat{u}(\theta)$ summing up to *X'* is still an increasing function of θ.

Under this scenario banks with low values of θ that are bad at risk handling will not be allowed to invest anything in the risky asset. However, since banks' profit functions remain unchanged and given that risk-weighted capital requirements or the leverage ratio remain the same, banks will have a strong incentive to pretend that they are better at risk handling and invest the same amount in *u* as before in order not to lose on profits. This suggests that the number of banks operating may not be reduced and since the aggregate risk is defined as the sum of total investment in the risky asset, the critical level of *X'* is likely to be surpassed. Moreover, the new liquidity buffers will not be adhered to. It seems that this type of regulation is not an effective mechanism in this case in line with the argument by von Thadden (2011, p. 47), who states that *"regulation in practice … does not necessarily aim at the asset side, but rather tries to make sure that assets are funded by a more resilient liability structure"*.

7 Discussion

Several important topics within the field of financial regulation deserve a discussion based on the theoretical model above. The first-best solution based on some of the described regulation mechanisms may guarantee financial stability under perfect information and secure in addition efficient risk sharing, optimal liquidity and capital buffers. It has been pointed out that *"liquidity risk and solvency risk are hardly separable"* (Perotti, Suarez, 2011, p. 4), but the discussion will nevertheless distinguish between the two concepts referring to the amounts of safe asset and capital respectively. The outlined model shows that under asymmetric information the first-best solution is unobtainable and certain tradeoffs are inevitable. What is important, however, is to what extent predictions of the model actually match currently observed empirical trends.

7.1 Predictions of the model

As demonstrated above, given informational asymmetry a combination of liquidity regulation together with capital requirements may guarantee financial stability given that the latter are set at a sufficiently high level. Of this reason the funding structure of financial institutions has been suggested to be of primary importance: *"banks ... that carry less leverage are less likely to experience distress"* (IMF, 2013, p. 132). However, since efficient risk sharing and optimal liquidity and capital buffers matter as well, it might still be *"impossible to implement any Pareto-efficient outcome using just capital requirements as the tool of prudential regulation"* (Hellmann et al., 2000, p. 148).

To begin with, "market capital requirements", if strong enough, may contribute to financial stability and more efficient risk sharing. Banks that invest more in the risky alternative will have to hold more capital in absolute amount. Intuitively, *"capital serves as a signaling mechanism to alleviate informational asymmetries between banks and their creditors"* (Disyatat, 2010, p. 727). Depending on the strength of these requirements different outcomes are possible. Since banks that are good at risk handling are able to generate higher profits for each amount of risky investment, they will naturally be able to pay a higher cost of capital. However, since the market does not take the banks' ability to handle risk into consideration directly, the optimality conditions can only be achieved by chance. In theory, this type of self-correcting mechanism may be compatible with the first-best arrangement

found under perfect information: increasing path of risky investments and decreasing path of risk-weighted capital requirements. However, there is nothing about this mechanism that guarantees that the critical level of aggregate risk will not be surpassed and that both capital and liquidity buffers will be optimal. Since market requirements function through some sort of collective force, it is likely that optimality will be difficult to achieve due to problems of coordination.

The second regulation alternative considered in the model above assigns an increasing path for risky investments, but fixes capital requirements at the same level for all banks. As mentioned before, this creates mimicking incentives, because with fixed cost of capital the only factor that can stop banks from investing more in the risky alternative is accelerating individual probability of going bankrupt that adds negatively to their NPV. Due to convexity of that function banks that are prescribed low levels of risky investments by the social planner will be the first in line to mimic better risk handling ability and increase the amount of risky assets. This is going to deteriorate both financial stability and efficient risk sharing. The social planner may want to prevent systemic crisis by making the path of risky investments flatter in the risk-handling ability. This may secure financial stability by holding the sum of aggregate risk below the critical level, but risk sharing inefficiency will not be improved on. If capital buffers are set high enough, the social planner may eliminate credit risk, but liquidity risk will remain an issue, because banks that are bad at risk handling will have incentives to *"compensate the loss in utility from the reduction in leverage with the choice of a riskier portfolio"* (Berger et al., 1995, p. 12) and will consequently end up with low liquidity buffers. A well-functioning interbank market or the Central Bank will then be needed in order to cope with the problem of liquidity shortage in cases of idiosyncratic shocks hitting banks that are bad at risk handling. Moreover, financial stability in this case will be achieved at the cost of large amounts of capital. This is somewhat similar to a proposal suggesting *"funding banks with equity rather than demand deposits"* (ibid., p. 7). If the path for risky investment is, for instance, flat, banks will invest the same in the risky alternative regardless of their risk handling ability. Since the aggregate risk must sum up to some predefined value and the path of risky investments is now flat instead of increasing, banks that are bad at handling risk will be able to invest more in the risky alternative than under the first-best solution. In this situation, if credit risk is to be eliminated, the social planner must opt for capital buffers that would be enough to cover losses of banks that are bad at handling risk. This means naturally that banks that are good at risk handling will have too high capital buffers. As pointed out by

Berger, Herring and Szegö (1995, p. 22), if the Modigliani-Miller *"proposition applied to banks this would be a costless solution"*, but, as mentioned above, empirical research has pointed at contradicting evidence.

The final regulation alternative considered in the model prescribes an increasing path for risky investments and same risk-weighted capital requirements for all banks, defined as a ratio of capital to risky investments. As described above, *"the regulator is informationally constrained in targeting individual bank characteristics"* (Perotti, Suarez, 2011, p. 4), so risk-weighted capital requirements that are decreasing in risk-handling ability turn out suboptimal due to same mimicking incentives. Moreover, the social planner realizes that financial stability may be achieved if the ratio of capital to risky investments is set high enough: a steeply increasing capital cost function in a combination with concave revenue function will under certain conditions deter banks that are bad at risk handling from increasing their risky investments. However, in this case two different scenarios are possible. On the one hand, the social planner may set capital requirements at the level that is optimal for the banks with the worst risk handling ability. This may secure financial stability, insure against credit and liquidity risks. However, banks that have the best ability to handle risk will under this scenario be likely to reduce their risky investments compared to the first-best solution. This may then lead to underinvestment. On the other hand, the social planner may opt for somewhat lower capital requirements in order to secure enough overall investment in the risky asset. As mentioned before, banks that are bad at handling risk will then be the first in line to increase their risky investments. This may still ensure financial stability in the sense that the overall investment in the risky alternative will be held below the predefined critical level, but will deteriorate efficient risk sharing and create credit and liquidity risks for the banks that are bad at risk handling. A well-functioning interbank market or the Central Bank may alleviate the problem of liquidity risk, but credit risk for banks with the worst risk-handling ability will remain an issue. It has been argued that the latter is actually more dangerous than liquidity risk, because *"if there is more equity and less debt on the balance sheet, liquidity concerns may not be as acute, because creditors have relatively fewer claims and the probability of insolvency is smaller"* (Admati et al., 2011, p. 2). Nevertheless, since there are no interconnections between banks in the model, there will be no direct spread of risk to other parts of the system in cases of idiosyncratic shocks hitting banks that are bad at risk handling. If the latter actually go bankrupt, this might be regarded as efficient. Still it can be easily imagined that this can lead to other costs: banks *"produce information about*

borrowers which is lost if they fail or leave the industry" (Berger et al., 1995, p. 14). Also, since the majority of banks hold enough liquidity and more capital under this arrangement than what is optimal under the first-best scenario of perfect information, bank panics may not escalate beyond the least capable banks.

Overall, the results suggest that with the regulation mechanisms above financial stability may only be achieved at the expense of large amounts of capital, efficient risk sharing, liquidity or credit risks. Such result is partly due to the fact that liabilities are regulated through what is known as bunching: in this case treating different abilities to handle risk through equal capital requirements. It is thus not surprising that the result is in line with the conjecture made by Perotti and Suarez (2011, p. 6), who argue that *"banks with better credit opportunities will be constrained, while the reduced systemic risk actually encourages banks with low credit ability ... to expand"*. The problem arises due to the fact that existing regulation offers no mechanism to secure truthful revelation of incentives under asymmetric information, while market capital requirements are not comprehensive enough so that they can be relied on. Moreover, since described regulation mechanisms do not secure first-best efficiency, their implementation may create need for even more regulation. For instance, if liquidity risks are to be improved upon with the help of the Central Bank, this can create further problems, such as moral hazard.

7.2 Current trends

The new Basel III standards are currently under way to its implementation, so the exact effect of the regulation mechanisms they offer is uncertain. The adjustment to new requirements may be happening gradually: *"banks have diverse funding patterns that change only slowly"* (IMF, 2013, p. 132). However, some of the emerging trends have already been discussed both in the theoretical literature and in financial reports produced by policy makers. Given the results of the theoretical model above, it is thus interesting to consider the discussion about the extent, to which the new Basel Accord might be able to secure financial stability and the tradeoffs it might produce.

To begin with, Basel III capital requirements *"alter the risk weights assigned to various assets to better align them with the risk incurred"* (IMF, 2012, p. 83). This has been done in response to the critique of the Basel II capital requirements being not attached to the

"right risks". Reformulation of what constitutes risky assets means that their amount in banks' balance sheets is likely to increase and with risk-weighted capital requirements in place it will be necessary to raise additional capital. This may improve banks' capital buffers and decrease credit risk. Thinking in terms of the model above this may be beneficial for banks that are bad at risk handling, because by redefining risky assets such mechanism will increase the total cost of capital and decrease the incentive to invest more in the risky asset. However, it has been observed that *"some distressed banks remain vulnerable because their equity capital levels are inadequate"* (IMF, 2013, p. 105). This might indicate that banks that are bad at risk handling have been slow to adjust to the new regulation requirements. For banks that are good at risk handling or for banks with significant investments in risky assets such reformulation may create an incentive to reduce risky investments together with absolute amount of capital. A trend of this sort has been confirmed empirically: *"early evidence suggests banks may be adjusting to capital requirements through "derisking" ... Banks have been able to build regulatory capital by substituting assets (taking on assets that need less required capital)"* (IMF, 2012, p. 83). Since *"risk-weighted capital ratios can increase by increasing regulatory capital (the numerator) or by reducing risk-weighted assets (the denominator)"* (Goodhart et al., 2004, p. 605), the observed trends suggest that banks have generally been trying to do the latter with various degrees of success. However, a reformulation of what constitutes risky assets may also generate distortions, because *"risk measurement is complex"* (ibid., p. 597) and *"the resulting requirements will become dense and difficult"* (ibid.). An additional mechanism dealing with risk attachment, the "leverage ratio", has therefore been introduced to *"act in tandem with the existing suite of risk-based capital ratios"* (IMF, 2012, p. 116). This will prevent capital from falling below some minimum level due to complexity of definitions. However, as discussed in the model above, the "leverage ratio" by itself may create incentives to invest more in the risky asset. This has actually been observed previously, when *"several jurisdictions relied solely on the leverage ratio, which created incentives for banks to allocate resources to higher-risk assets"* (ibid.). Since the model above only deals with pure equity and does not illustrate the effect of both risk-weighted capital requirements and leverage ratio, it is unclear whether this regulation mechanism might generate the same type of incentives. Moreover, highly leveraged institutions may not necessarily suffer from credit risk, which capital is aimed at combatting. As pointed by Morris and Shin (2008, p. 243), *"the higher leverage of investment banks reflects both the relatively low credit risk of the assets held and the short-term nature of much of their claims and obligations"*.

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The level of risk-weighted capital requirements has been left unchanged by Basel III agreements, remaining at 8% as previously. However, because of *"major changes in the composition of capital and in the definition of eligible capital, many banks will nonetheless have to raise capital to meet the new standards"* (IMF, 2012, p. 116). Thinking in terms of the model above this might imply stricter capital requirements and a steeper capital cost function. This will, on the one hand, make banks that are bad at risk handling decrease their risky investments and improve on risk sharing. On the other hand, banks that are good at risk handling may want to decrease their risky investments as well, since for them the new capital buffers may be too high. If there is reason to believe that capital requirements are set at a high enough level, this may limit *"the amount of maturity transformation banks can provide"* (von Thadden, 2011, p. 47) and lead to a *"stability-profitability trade-off"* (ibid.). The result could be less provision of banking services and perhaps even some sort of underinvestment. In this situation, as stressed by Berger, Herring and Szegö (1995, p. 54), capital requirements would *"involve a long-run social tradeoff between the benefits of reducing the risk of the negative externalities from bank failures and the costs of reducing bank intermediation"*. Banks that are good at risk handling might then start looking for profits elsewhere and either turn to complex financial innovation or push *"bank-like activities into some less-regulated nonbank financial institutions (the shadow banking system)"* (IMF, 2012, p. 77). Of course, this would mean that the measure of systemic risk might become useless, because it would not account for risky investments in the non-bank sector. As noticed by Hellwig (2010, p. 3), before the financial crisis *"excessive maturity transformation was due to the development of a shadow banking system"*. The latter is *"different than depository institutions, in that the activity involves the repo market, where depositors and lenders are individually matched"* (Gorton, 2009, p. 14). Current regulation requirements offer no mechanism of monitoring or controlling the non-bank sector and expansion of this sector will create need for more regulation. At the same time it is unclear how far this tendency might go, since banks may retain some advantages over non-bank financial institutions, such as *"access to central bank liquidity support"* (IMF, 2012, p. 85). Nevertheless, abstracting from the non-bank sector, if there is reason to believe that existing capital requirements are still not set at a high enough level, the regulatory community *"should aim for substantially higher regulatory capital, well above ten percent and perhaps even closer to the twenty or thirty percent"* (Hellwig, 2010, p. 11) in order to secure financial stability. As demonstrated by the model above low capital requirements give banks that are bad at risk handling strongest incentives to increase their

risky investments and push the aggregate risk beyond the critical level. This view is shared by Harris and Raviv (2013, p. 4) who argue that due to lenient capital requirements *"Basel III Accords ... will not eliminate excessive risk taking"*.

Uncertainty about the sufficiency of current capital requirements arises due to the fact that information used to calculate such requirements is in reality private and often reported by the banks themselves. As illustrated by the model above, in order to set optimal capital requirements, regulators need detailed information on banks' profit function and the individual probability of going bankrupt, not to mention information about risk handling ability. Since the introduction of Basel II framework regulation of the financial sector has been based on an idea that "*banks are better informed about their risks than regulators*" (Santos, 2000, p. 20). Financial institutions have therefore been allowed to make use of internal models, better known as Internal Ratings-Based Approach, in order to assess credit risks. The problem with this mechanism, however, is connected to truthful revelation of information. By underreporting real profits, exaggerating capital costs, manipulating risks through internal modeling or other "cosmetic adjustments" banks may affect regulation requirements and there is reason to believe that they will attempt to do so. As illustrated in the model above, degree of convexity and concavity of the functions constituting banks' NPV are central for their mimicking incentives. Hellwig (2010, p. 9) argued that *"the regulatory community knew that risk calibration was mainly a tool to reduce capital requirements"*. Moreover, *"the very attempt to calibrate regulatory capital towards measured risks might be responsible for the insufficiency of bank equity capital"* (ibid., p. 5).

The absence of regulation of banks' refinancing risk has been considered *"a critical gap in the Basel II framework"* (Perotti, Suarez, 2011, p. 3). Attempts at its correction proposed by the Basel III Accord have already been called *"the most daring and novel rules concerning bank liquidity"* (von Thadden, 2011, p. 43). In the model above banks have an incentive to overinvest in the risky asset under competitive equilibrium due to existence of a negative externality. Optimal liquidity buffers are secured through distribution of prescribed investment in the risky alternative. This is somewhat different from reality, since Basel III does not aim at regulation of assets directly, but rather *"targets the bank's potential maturity mismatch"* (von Thadden, 2011, p. 47). Regulation of assets in the model contributes to less investment in risky assets and secures optimal liquidity buffers. This may reduce reliance of financial institutions on the interbank market or provision of liquidity by the Central Bank.

Such development may prove beneficial for the financial system in the future, since *"a key problem in the 2008 crisis, as in the looming European banking crisis of 2011, has been the failure of the interbank market"* (ibid., p. 48). However, as discussed in the model above, large enough liquidity buffers for all types of banks can only be secured if risk-weighted capital requirements are set at the level where least capable banks do not have an incentive to mimic better risk-handling ability. If there is reason to believe that capital requirements are below that level, then banks with poor risk-handling ability will end up with suboptimal liquidity buffers. Some arrangement is then needed in order to secure provision of liquidity in times of stress. It has been observed that after the already mentioned failure of the interbank market Central Banks *"have substituted for interbank lending"* (IMF, 2012, p. 95). At the same time, as argued by Perotti and Suarez (2011, p. 6), *"liquidity requirements would have to be increased in good times and reduced in bad times so as to avoid making them a source of further banking system procyclicality"*. The Basel III does not currently address procyclicality of liquidity buffers. Furthermore, if one abstracts from effects of capital requirements for a moment, restrictions on assets are likely to create incentives to look for profits elsewhere and make banks turn to the non-bank sector. Since *"nonbank financial institutions are largely unaffected by these changes, ... [they] could benefit from moving of business in their direction"* (IMF, 2012, p. 86). A trend of this sort has already been confirmed empirically: *"progress on implementing the Basel III liquidity rules in a domestic context is prompting more nontraditional activities, especially larger holdings in other earning assets"* (ibid., p. 110). As mentioned before, increased level of activity in the non-bank sector might distort the measure of aggregate risk and deteriorate financial stability.

The above trends suggest that financial regulation faces several important challenges. *"The current approach to systemic regulation implicitly assumes that we can make the system as a whole safe by simply trying to make sure that individual banks are safe"* (Brunnermeier et al., 2009, p. vii). Achieving this goal comes together with various inefficiencies that the regulators have to choose between. Because of countervailing incentives, the financial sector may either end up with too lenient regulation requirements or face migration of activity to the non-banking sector. Needless to say, both cases pose a threat to financial stability.

8 Conclusion

The purpose of this thesis has been to explore various issues connected to financial stability and the tradeoffs that the existing regulation mechanisms may generate. The starting point of the discussion has been a theoretical model representing an aggregation of financial institutions differing in their ability to handle risk. It was shown that in an unregulated equilibrium investment in risky assets generates a negative externality, which in turn poses a threat of systemic collapse. As a remedy to this potential problem three different regulation mechanisms have been considered, corresponding roughly to the liquidity ratio, risk-weighted capital requirements and the leverage ratio, as described by the Basel III Accord. It has been demonstrated that a combination of liquidity ratio and risk-weighted capital requirements that decrease in ability of risk handling may produce a Pareto-efficient outcome under perfect information. When information is asymmetric, however, banks get incentives to mimic better risk-handling ability in order to increase profits. A combination of the outlined liquidity regulation and leverage ratio is particularly favorable for such mimicking, since the bank size is assumed to be fixed in the model making the total cost of capital exogenous. In this case financial stability may be achieved at the cost of inefficient risk sharing and suboptimal liquidity and/or capital buffers depending on the strictness of capital requirements. Liquidity regulation in a combination with risk-weighted capital requirements may also generate mimicking incentives, especially if capital requirements are decreasing in risk handling ability. If, on the other hand, capital requirements are set at the same level for all banks and are used in combination with liquidity regulation, financial stability may be secured at the cost of inefficient risk sharing, suboptimal liquidity and capital buffers for some banks or, alternatively, general underinvestment. The predictions of the model regarding various tradeoffs seem to match several of the currently observed trends in connection with implementation of the Basel III Accord. An introduction of stricter definitions of what constitutes risk and capital has given rise to adjustment behavior, such as decreasing risky investments. Capital, on the other hand, has been slow to adjust. Even though derisking of asset portfolios may contribute to larger capital and liquidity buffers and in that way promote financial stability, there has been a concern that search for profits will drive bank activity to the unregulated non-bank sector. At the same time it is unclear whether current capital requirements are set at a high enough level, which is needed to prevent systemic collapse.

The conclusions made in the present work have been based on a particular theoretical construction, which is not without its limitations. In particular, the model treats *ability* to handle risk as a source of bank heterogeneity. Since it is assumed that banks cannot improve on their risk handling, it is perhaps not surprising that when faced with regulation requirements that reduce their profits, financial institutions choose to adjust through mimicking. If *effort* and not *ability* was, for instance, the main source of heterogeneity, it would probably be desirable to motivate banks instead of holding them in place and could result in different conclusions. Furthermore, the model adopts a certain mechanism, through which systemic risk endangers economy, namely the aggregate investment in risky assets. In reality, it may be well other factors, such as spillover effects, that constitute a systemic threat. It has been pointed out, for instance, that *"Lehman's end-2007 balance sheet as a whole consisted of precisely the types of assets and liabilities that have low credit risk but high systemic impact"* (Morris, Shin, 2008, p. 243). The absence of the interbank market is thus one of the main limitations of the present work. Finally, the model treats both assets and liabilities as consisting of just two alternatives. Of this reason it is possible to view restrictions on risky assets as a type of liquidity regulation. In reality, however, banks operate with many different types of risky assets, so restricting the latter would not necessarily affect liquidity buffers. Similarly, since the model only distinguishes between equity and demand deposits, it is not possible to illustrate the effect of risk-weighted capital requirements and leverage ratio simultaneously. It is perhaps not surprising that the leverage ratio, when viewed by itself, does not produce desired effects. After all, it is precisely the existence of different types of capital, such as subordinated debt and hybrid capital, which has justified the introduction of the leverage ratio in the Basel III Accord.

The results of the present paper demonstrate that financial stability is a complex issue, and both micro- and macroprudential regulation may be needed in order to prevent future financial crises. As pointed out by Morris and Shin (2008, p. 259), *"taking care of the solvency of each individual institution ensures the stability of the system is not useful, because it does not address spillover effects".* Still, if some of the illustrations in the present work are correct, the microprudential regulation of the Basel agreements may need to be further improved on. Until the Basel III Accord is fully implemented it remains to see whether it has succeeded in dealing with these issues.

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