Banking Regulation in the Aftermath of the Crisis: Towards a More Stable Financial System?

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Abstract

This dissertation is organized into five chapters and analyzes three instruments of banking regulation that have particularly attracted attention after the 2007/09 financial crisis. The second chapter investigates theoretically the role of capital regulation as the most common regulatory tool. It shows in a general equilibrium framework that requiring a higher capital adequacy does not necessarily lead to a more stable banking system if banks cannot immediately issue new equity. On the one hand, stricter capital requirements force banks to have 'more skin in the game,' reducing moral hazard and resulting in a less risky asset choice. On the other hand, increasing equity requirements can result in a selection problem: Individual banks with the highest ability to run risky investment projects are not allowed to absorb the entire supply of deposits. Hence, qualitatively worse agents become banks which results in a decrease in the average ability of banks. The third chapter addresses the usage of the credit-to-GDP gap as the determining factor of the macro-prudential tool of a countercyclical capital buffer and investigates whether the regulatory reform of introducing countercyclical capital buffer based on the credit-to-GDP gap is appropriate for preventing or mitigating financial distress. It can be shown that there is a positive correlation between the credit gap and a bank's contribution to systemic risk as well as a strong evidence for a positive correlation between excessive credit and bank asset risk. Thus, while the regulatory measure of countercyclical capital buffer can be effective in preventing financial distress arising from the exogenous increase in systemic risk, it is doubtful whether it also succeeds in reducing banks' incentives to engage in high-risk assets. The fourth chapter of this thesis analyzes the too-big-to-fail hypothesis. It is argued that bank size is not a satisfactory measure for the market's perceived bailout probability of individual banks but that these probabilities depend on a bank's systemic importance. The results of this chapter indicate a significant decrease in CDS spreads for more systemically relevant institutions, but no significant effect of relative bank size in countries with a zero debt level, once we control for systemic risk. However, the effect of bank size increases in the home country's debt ratio, and the overall effect of relative bank size becomes positive already at moderate debt ratios. These findings suggest that banks are too systemic to fail (TSTF) rather than too big to fail, and that they might become too big to save if the bank's home country is burdened with high levels of debt.

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Abstract

Die vorliegende Dissertation gliedert sich in fünf Kapitel und analysiert drei Instrumentarien zur Regulierung von Banken, welche im besonderen Maße nach der Finanzkrise von 2007/09 Beachtung fanden Das zweite Kapitel untersucht in einem theoretischen Modellrahmen den Einfluss von Eigenkapitalregulierung im allgemeinen Gleichgewicht. Es zeigt sich, dass eine höhere Eigenkapitalausstattung nicht zwangsläufig zu einem stabileren Bankensystem führen muss, wenn Banken in der kurzen Frist kein weiteres Eigenkapital beschaffen können. Auf der einen Seite führen strengere Eigenkapitalregeln zu einem Abschwächen des moralischen Fehlverhalten und einer weniger riskanten Projektauswahl. Auf der anderen Seite jedoch resultiert aus strengeren Eigenkapitalvorschriften ein Selektionseffekt: Banken mit der höchsten Befähigung ist es nicht erlaubt, das gesamte Einlagenangebot abzuschöpfen, was dazu führt, dass qualitativ schlechtere Agenten in den Bankenmarkt eintreten und dadurch die durchschnittliche Leistungsfähigkeit im Bankenmarkt abnimmt. Das dritte Kapitel adressiert den Gebrauch des Credit-to-GDP Gaps als bestimmender Faktor für antizyklische Kapitalpuffer als makroprudenzielles Regulierungsinstrument und untersucht somit, ob die Einführung von antizyklischen Kapitalpuffern ein geeignetes Instrument zur Verhinderung einer Notlage des Finanzsystems sein kann. Es zeigt sich eine positive Korrelation zwischen dem Kredit Gap und dem Beitrag zum systemischen Risikos von Banken sowie eine starke Evidenz für eine positive Korrelation zwischen einer exzessiven Kreditvergabe und dem Anlagerisiko von Banken. Während antizyklische Kapitalpuffer erfolgreich in der Bekämpfung von Schieflagen des Finanzsystems hervorgerufen durch einen Anstieg des systemischen Risikos sein können, so ist es fraglich, ob die Maßnahme die Anreize von Banken, in riskante Projekte zu investieren, reduzieren kann. Das vierte Kapitel analysiert die weitverbreitete too-big-to-fail Hypothese. Es wird argumentiert, dass die Größe einer Bank kein zufriedenstellendes Maß für die vom Markt wahrgenommene Wahrscheinlichkeit für die Rettung individueller Banken darstellt, sondern dass diese Wahrscheinlichkeit von der systemischen Relevanz der Bank abhängt. Das Kapitel zeigt einen signifikanten Rückgang von CDS Preisen in der Systemrelevanz einer Bank, während sich kein signifikanter Effekt für die Größe einer Bank in Ländern mit einer Staatsverschuldung von Null herausstellt, sofern für das systemische Risiko kontrolliert wird. Jedoch ist der Effekt der Bankengröße ansteigend in der Staatsverschuldung des Heimatlandes und der Gesamteffekt der relativen Bankengröße wirkt sich bereits für einen moderaten Verschuldungsgrad des Heimatlandes positiv auf CDS Preise aus. Dieses Ergebnis deutet darauf hin, dass Banken *zu systemisch zum Scheitern (too systemic to fail)* sind anstatt *zu groß zum Scheitern (too big to fail)* und dass sie sogar zu groß für eine Rettung angesehen werden, falls ihr Heimatland bereits von einer hohen Staatsverschuldung belastet ist.

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Chapter 1

Introduction

Banks play a crucial role in the functioning of the economy. They improve capital allocation by acquiring information about firms and producing information ex ante about possible investments, they facilitate the management of inter-temporal, cross-sectional and liquidity risk, and they mobilize and pool savings to exploit economies of scale. Comparing banks with manufacturing or service-sector firms, two reasons can be given why banks are special. First, there are the traditional banking activities to grant long-term, information sensitive loans and to finance them through short-term, non-securitized deposits from the public. While these functions mitigate the problem of asymmetric information between lenders and borrowers, they do not completely solve the market failure of asymmetric information because small depositors have neither the incentive nor the ability to assess the soundness of banks. Second, while the default of a manufacturing or service-sector firm tends to strengthen the competitor firms, the failure of a bank weakens other financial institutions, financial markets with which they were involved, and the wider economy. These two reasons of protecting depositors and negative externalities from the default of one bank on the financial system call for a proper regulation of banks.

Hardly regulated before the Great Depression of the 1930s, the banking industry soon after became one of the most strongly regulated sectors in the economy. The strong recession during this period was attributed to the breakdown of the financial system and the accompanied disruption of credit channels, and it was the general conclusion that banking supervision and regulation could aim to eradicate most of the practices that were responsible for the crisis. However, costly financial crises have emerged repeatedly in both industrialized and developing countries, with the global financial and banking crisis in 2007-09 being the largest financial shock since the Great Depression. Thus, despite many enhancements over time, the regulatory framework that was in place before the recent crisis suffered from a number of weaknesses.

The various regulatory measures that have been proposed, implemented, or discussed in response to the 2007-09 financial turmoil call for research investigating their effectiveness. This thesis analyzes three such instruments of banking regulation that have particularly attracted attention after the recent financial crisis. The thesis is based on three studies and organized into five chapters.

One critique of the pre-crisis regulatory framework is the weak capitalization of banks. On the one hand, many well-known scholars who argue in favor of stricter capital requirements stress the impact of equity on the quality on banks' lending decisions.[1] According to this argument, higher equity provides bankers with the right incentives and thus mitigates moral hazard. Moreover, the *Geneva Report on the World Economy 11* on *The Fundamental Principles of Financial Regulation* calls for higher equity requirements by arguing that systemic risk might increase substantially if low levels of capital act as a trigger for prompt corrective action. On the other hand, most arguments against higher capital requirements, which were discussed in the general public and particularly promoted by the banking lobby, refer to a potential credit crunch and thus, on a quantitative effect of capital regulation.

The second chapter of this thesis, which is based on joint work with Christian Seckinger, investigates theoretically the role of capital regulation as the most common regulatory tool and the most intensely debated issue in the aftermath of the crisis. This chapter shows in a general equilibrium framework that an unintended consequence may result from an increase in capital requirements if banks cannot immediately raise new equity. In a theoretical setup where banks differ with respect to an unobservable ability to successfully run a risky investment project, the economy might suffer simultaneously from a moral hazard problem and a selection problem among agents. On the one hand, stricter capital requirements force banks to have 'more skin in the game,' reducing moral hazard and resulting in a less risky asset choice. On the other hand, increasing equity requirements can result in a selection problem if banks cannot immediately raise new equity. Individual banks with the highest ability to run risky investment projects are not allowed to absorb the entire supply of deposits. Hence, qualitatively worse agents become banks which results in a decrease in the average ability of banks. Thus, in a general equilibrium framework, requiring a higher capital adequacy does not necessarily lead to a more stable banking system if banks cannot immediately issue new equity.

Many scholars have also criticized the lack of macro-prudential instruments as a second weakness of the former regulation. According to the *Geneva Report on the World Econ-*

[1]See, for example, a letter signed by 20 leading academics that was published in the Financial Times (2010) on November 9, 2010, and Admati, DeMarzo, Hellwig, and Pfleiderer (2011).

omy 11 on *The Fundamental Principles of Financial Regulation*, "[making] the system as a whole safe by simply trying to make sure that individual banks are safe [...] sounds like a truism, but in practice it represents a fallacy of composition."(Brunnermeier, Crockett, Goodhart, Persaud, and Shin (2009), p.i) Therefore, a general increase in equity as a micro-prudential regulatory tool with the objective to fight the moral hazard behavior of banks, should be supplemented by macro-prudential regulation that aims to safeguard the system as a whole. The most recent regulatory framework, Basel III, adds a number of such macro-prudential instruments to the regulators' toolbox.

One macro-prudential regulatory measure that has been introduced in Basel III is the countercyclical capital buffer. According to this concept, banks have to hold additional equity for exposures in countries where the provision of credit is considered to be excessively large. The proposed regulation asks national authorities to set a countercyclical buffer rate for exposures in their country on the basis of the gap between the ratio of the actual level of credit to the private sector to GDP and the long-term trend of this ratio. It has been agreed on using the credit-to-GDP gap as the determining factor of the countercyclical buffer rate since this measure has been found to be the best single indicator for the build-up phase to financial crises within a three-year horizon in a number of studies (see, for example, Drehmann, Borio, and Tsatsaronis (2011) or Detken, Weeken, Lucia, Bonfim, Boucinha, Castro, Frontczak, Giordana, Giese, Jahn, Kakes, Klaus, Lang, Puzanova, and Welz (2014)).

The third chapter of this thesis addresses the usage of the credit-to-GDP gap as the determining factor of the macro-prudential tool of a countercyclical capital buffer. More precisely, the goal of this chapter is to analyze, on the bank level, the causes for the good performance of this measure in predicting financial distress. Consequently, it investigates whether the regulatory reform of introducing countercyclical capital buffer based on the credit-to-GDP gap is appropriate for preventing or mitigating financial distress. The first question this chapter addresses is the relationship between excessive credit and banks' contribution to systemic risk. The result indicates a positive correlation between the credit gap and $\Delta CoVaR$, a measure of a bank's contribution to systemic risk, which has been introduced by Adrian and Brunnermeier (2011). The analysis, however, provides only weak evidence that this correlation is not purely driven by variables determining the economic context, as for example the growth rate of GDP as well as country-specific property prices. The second question this chapter addresses is whether banks located in a credit-booming economy endogenously increase their asset risk. The analysis provides strong evidence for a positive correlation between excessive credit and bank asset risk that cannot be explained by the economic context. The findings of this chapter suggest that the credit-to-GDP gap performs well in predicting financial crises due to both a shift in bank behavior and an increase in banks' contribution to systemic risk, which is partly driven by exogenous factors such as the economic context. Thus, while the regulatory measure of countercyclical capital buffer can be effective in preventing financial distress arising from the exogenous increase in systemic risk, it is doubtful whether it also succeeds in reducing banks' incentives to engage in high-risk assets.

A third critique of pre-crisis regulation is the malfunctioning of market discipline, a concept that was introduced as the third pillar of the Basel II framework. Critics argued that banks benefited strongly from implicit bailout guarantees and from diminishing market discipline, especially during the financial crisis (see Hett and Schmidt (2013)). Since bank debt was implicitly fully insured by state guarantees, there were no incentives for bank debtors to punish misbehavior of financial institutions. In this respect, particularly strong emphasis was put on the size of banks. Since it was assumed that the probability for receiving financial support in times of crisis increases with *bank size*, many institutions had an incentive to grow until they reached a 'too-big-to-fail' status.

The fourth chapter of this thesis, which is based on joint work with Isabel Schnabel and published in Economic Policy (Barth and Schnabel (2013)), analyzes this too-big-to-fail hypothesis. It is argued that bank size is not a satisfactory measure for the market's perceived bailout probability of individual banks but that these probabilities depend on a bank's systemic importance. We therefore differentiate the effect associated with bank size from the impact of bank's systemic risk contribution, measured by the $\Delta CoVaR$, on CDS spreads. The results presented in this chapter indicate a significant decrease in CDS spreads for more systemically relevant institutions, but no significant effect of relative bank size in countries with a zero debt level, once we control for systemic risk. However, the effect of bank size increases in the home country's debt ratio, and the overall effect of relative bank size becomes positive already at moderate debt ratios. These findings suggest that banks are too systemic to fail (TSTF) rather than too big to fail, and that they might become too big to save if the bank's home country is burdened with high levels of debt. This chapter further investigates the importance of the too-systemic-to-fail problem over time. It is shown that TSTF has not been priced in the CDS market before the onset of the financial crisis, but that there is a strong and significant effect of systemic importance after the outburst of the financial crisis. This effect again weakens after the non-bailout of Lehman Brothers and the collapse of the Icelandic banking system, which emerges in consequence of the incapability of the Icelandic government to bail out its three largest banks. This sequence of events is interpreted as a double wake-up call for investors: With the advent of the financial crisis in 2007, investors were reminded of the risks in banking and of the fact that some banks were more likely to be bailed out than others. The Lehman non-bailout and the Icelandic crisis then showed that governments may not always be willing or able to bail out even systemic institutions. Thus, this chapter warns against a too strong reliance by policymakers on bank size as a measure of systemic importance and supports the use of measures trying to explicitly capture the externalities from a bank's default on the remaining financial system.

Chapter five of this thesis summarizes the main findings and provides a final discussion about the implications that arise from these results.

Chapter 2

Capital Regulation with Heterogeneous Banks

- Unintended Consequences of a too Strict Leverage Ratio -

This chapter is based on joint work with Christian Seckinger.

2.1 Introduction

Hardly any issue has been discussed as intensively in the most recent years as the appropriate amount of bank equity. The European Systemic Risk Board (2014a), for example, issued quite recently a handbook on operationalizing macro-prudential policy in the banking sector with one key instrument to address excessive credit growth and leverage being the leverage ratio. Most arguments in the public as well as in the academic literature refer to a quantitative effect of too strict regulation,[1] and only little is said about potential qualitative effects. While Admati, DeMarzo, Hellwig, and Pfleiderer (2011) argue that higher capital requirements improve the quality of bank lending decisions, we provide a

[1]For example, in 2009, Josef Ackermann, former CEO of Deutsche Bank, stated in an interview that "more equity might increase the stability of banks. At the same time however, it would restrict their ability to provide loans to the rest of the economy", see Ackermann (2009). On the other hand, Admati, DeMarzo, Hellwig, and Pfleiderer (2011) point out that the common arguments against too much equity are either fallacies, irrelevant facts, or even myths. In particular, they argue that higher capital requirements do not force banks to reduce lending activities since higher regulatory equity does not require to set capital aside or to hold additional reserves.

general equilibrium framework coming along with a second countervailing effect of capital regulation on the quality of the banking system.

We argue that an economy with heterogeneous banks may suffer simultaneously from a moral hazard problem and a selection problem among individuals. As the analysis of Admati, DeMarzo, Hellwig, and Pfleiderer (2011) proposes, we restrict the tools of the regulator to minimum capital requirements. While stricter capital requirements make banks to have more 'skin in the game' and thus reduce the moral hazard problem, they also increase the selection problem. Individuals who are best able to run banks are not allowed to absorb the entire supply of debt when they cannot immediately raise new equity, which could arise for example due to a debt overhang problem. Hence, qualitatively worse agents become banks. In addition, the size of the banking sector is an important factor, as the arguments of the banking lobby and the literature related to the problem of a credit crunch suggest. In our model, the agents' endogenous decision whether to open a bank or to become a debtor implies the efficient size of the banking sector. Only very strict capital requirements may also reduce the volume of invested funds, which forces individuals to invest inefficiently into a risk-free asset instead of depositing with a bank. We conclude that the regulator must try to balance the three effects in order to maximize the efficiency of the economy. We therefore incorporate the view of Admati, DeMarzo, Hellwig, and Pfleiderer (2011) that strict capital requirements may be adequate to solve moral hazard problems, but we present a channel beside the common arguments how capital requirements may affect negatively the efficiency of the economy. Particularly, it may reduce the size of the banking sector and introduce a severe selection problem.

This chapter enters a large list of papers dealing with the relationship of banking regulation and bank risk-taking behavior. This strand of the literature, however, has not concluded to a clear evidence so far. Within the theoretical literature, a positive relationship between regulation and risk-taking has been found in, e.g., Koehn and Santomero (1980), Kim and Santomero (1988), Rochet (1992), Gennotte and Pyle (1991), Blum (1999), Hakenes and Schnabel (2011), while the contrary result is present in, e.g., Furlong and Keeley (1989) and Hellmann, Murdock, and Stiglitz (2000). Empirically, Shrieves and Dahl (1992), Aggarwal and Jacques (2001), and Rime (2001) identify a positive relationship between regulation and risk-taking, while Jacques and Nigro (1997) find lower risk levels in response to an increase in banks' capital. Our results relate to the findings in the theoretical work of Calem and Rob (1999) and Diamond and Rajan (2000) and the empirical result of Heid, Porath, and Stolz (2004), who show that the effect of regulation on bank risk-taking is ambiguous. As most of the existing theoretical work relies on homogeneous banks, we argue similar to VanHoose (2007) that a homogeneous banking sector is inconsistent with reality and that there are many dimensions along which banks differ.[2] Within a world of heterogeneous banks, there are some agents replying to stricter regulation with a lower risk-taking while other agents increase their risk structure.

Regarding the theoretical setup, this chapter of the thesis is closely related to the work of Morrison and White (2005). In their paper, agents make their decision about collecting deposits from other individuals and opening a bank, investing only their own funding resources into a risky project, or depositing their initial endowment with a bank. Individuals receive some fee per unit deposits when they decide to open a bank, but only a portion of individuals has the ability to monitor an investment project and thus, has a higher probability to run this project successfully. In order to examine the role of banking regulation, they include a welfare maximizing regulator armed with three policy instruments. She can define minimum capital requirements, she awards licenses for running a bank, and since screening applicants is not perfectly possible, the regulator can close a bank if there is some indication that it is managed by a low-ability manager. One key assumption is that the regulator always assigns as many licenses as there are sound individuals. The goal of her actions is to incentivize high-ability individuals to run a bank and monitor the risky investment projects while the low-ability individuals deposit their funds with a bank. So the regulator tries to solve a moral hazard problem and an adverse selection problem, but also controls the size of the banking sector. Morrison and White (2005) show that if the costs for monitoring are low, there is no need for a regulator, since the high-ability individuals will run banks and monitor their risky projects while the low-ability individuals will deposit their endowment with a bank. For higher values of monitoring costs, however, there is a need for a regulator since on the one hand, high-ability individuals may not have incentives to monitor any longer (moral hazard) and on the other hand, low-ability individuals want to run a bank (adverse selection). It follows that a stricter regulation in terms of auditing improves the moral hazard problem and tighter capital requirements mitigate the adverse selection problem since it pushes the low-ability banks out of the market. In addition, it decreases the size of the banking sector, leading to an inefficiently small amount of monitored investment projects.

However, by slightly changing the framework of Morrison and White (2005), we demonstrate that the selection effect might be countervailing to the moral hazard effect.[3] Par-

[2]For example, Demirgüç-Kunt and Huizinga (2010) show that banks are heterogeneous with respect to their fee income share and that those banks with large non-traditional banking activities on the one hand tend to have a higher return on assets, but on the other hand tend to be individually more risky.

[3]While in Morrison and White (2005) the number of banks is fixed and hence, for every 'bad' bank a 'good' bank must disappear, this effect is a classical adverse selection. In our model, however, market entry by a 'bad' bank does not force a 'good' bank to disappear. Therefore we call the adjustment of the average ability of bankers selection effect.

ticularly, we endogenize the deposit rate and introduce an outside option to the agents in a way that they can also invest into a risk-free asset (costless storage technology). Moreover, the regulator's single tool is to define a minimum capital adequacy ratio. It appears that the deposit market allocates, for a given regulation, the individuals into banks and depositors in a welfare maximizing way. In our model, auditing as well as predefining a fixed number of banks are not instruments of the regulator's toolbox, contrary to Morrison and White (2005). We abstract from those tasks since they do not provide a realistic reflection of current banking regulation. First, although the current regulation demands a large set of information and requirements before opening a bank, they do not limit the licenses up to a particular number, see Board of Governors of the Federal Reserve System (2013). Second, to our opinion, auditing in terms of closing a bank before the realization of any return is rather unrealistic. In Morrison and White (2005), auditing is modeled as bank closing after evaluating its business strategy in terms of investment and monitoring choice. In general, however, the regulator has the power to close a bank only in response to an malfunction which is hardly detected ex ante a project return has realized.

More precisely, we consider a continuum of individuals, which are heterogeneous with respect to an unobservable ability to successfully complete investment projects, drawn from the unit interval. The individuals have the same decision set as in Morrison and White (2005) with an additional outside option. They can invest their initial endowment into a risk-free asset, deposit it with another individual or open a bank by taking deposits and investing into a risky project. It turns out that individuals with a high success probability decide endogenously to invest into a risky investment project, and individuals with a low success probability prefer to lend their funds in the deposit market to 'better' individuals. The deposit rate is endogenized and tries to balance demand and supply. We then show that the deposit market solves the selection problem, since it serves as a vehicle to transfer funding resources to those individuals with highest abilities to successfully run investment projects. We further introduce in our model a moral hazard problem, which arises due to limited liability. Giving banks the possibility to blow up their balance sheet by increasing the amount of deposits taken, banks increase project risk to mitigate their success probability in order to decrease the expected value of depositors' claims against the bank. In order to illustrate the impact of various levels of capital requirements on the size, the composition and the riskiness of the banking sector, we assume an exogenous regulator whose only tool is to set the minimum capital requirements for banks.[4] It turns out that the selection problem and the moral hazard problem have countervailing

[4]One could endogenize the role of the regulator, e.g., by giving him the goal to maximize aggregate payoff of the economy and at the same time minimize the potential negative spillover effects to depositors. Weighting these goals differently, one would obtain different levels of capital requirements.

effects on banks' riskiness. The economic argument is straightforward. If the regulator strengthens regulation by demanding higher capital requirements, she decreases ceteris paribus the demand for deposits. The resulting decline of the deposit rate incentivizes some depositors to open a bank, hence increases the selection problem. Since those banks unambiguously have a lower ability than the already existing banks, the average ability of bankers decreases, increasing average riskiness of banks. However, a lower leverage and a decrease in funding costs leads banks to decrease project risk, mitigating the moral hazard problem. Hence, the overall effect of regulatory changes on aggregate project risk is ambiguous. The result holds as long as capital requirements are not too strict, so that all individuals prefer running a bank or depositing their funds rather than investing into the risk-free asset. If regulation is very strict, demand in the deposit market is too low to imply an equilibrium interest rate for which all individuals want to participate in the deposit market. Hence, the volume of managed funds in the banking sector shrinks, imposing a size effect. In addition, the moral hazard effect and the allocation effect are no longer countervailing. Although stricter regulation then mitigates both selection problem and moral hazard problem, the size effect is dominant so that the benefits of a larger banking sector always outweigh the costs of a more pronounced moral hazard behavior and a lower average ability of the banking sector.

Our model suggests that the degree of heterogeneity plays a crucial role in determining the optimal minimum capital requirements. Since the strength of the allocation effect increases and the moral hazard effect diminishes for higher dispersion of the individuals' ability, rising heterogeneity implies decreasing optimal capital requirements. Differences in the quality of bank lending decisions give rise to gains of specialization that improve the quality of banks and decreases the interest rate on deposits.

We conclude that, in a general equilibrium framework, the deposit market provides an important channel through which banking regulation can control the selection and the moral hazard problem in the banking sector. In particular, we show that the regulator faces the challenge to balance gains from a beneficial allocation of funding resources and costs from moral hazard behavior appropriately for relatively loose capital requirements. For very strict requirements, however, she must consider an additional size effect, although the problems of selection and moral hazard can be solved simultaneously. By endowing the regulator with a more realistic toolbox and endogenizing the deposit rate as well as the number of banks in the banking sector, we therefore challenge the results of Morrison and White (2005) who argue that, under the assumption of an exogenously given number of banks, stricter capital requirements solve the selection and moral hazard problem simultaneously, coming however at the cost of a smaller banking sector. Our model coincides with this conclusion only for very strict capital requirements and only due to the storage technology opportunity. However, relaxing the regulatory standard shows diametrical results. If regulation is appropriately designed so that the size of the banking sector is maximized, the selection problem and the moral hazard problem are countervailing. Higher capital requirements solve the moral hazard problem but make the selection problem more severe. Hence, the regulator must try to balance the two effects in order to achieve the maximum aggregate payoff in the economy.

This chapter is organized as follows. In section 2.2, we first introduce the basic setup of the theoretical model as well as the decision structure of all agents. Section 2.3 describes the payoffs and business opportunities, illustrates the allocation effect, and introduces the agents' outside options. We then present the equilibrium outcome in section 2.4 and discuss the impact of capital requirements on the simultaneous problem of selection among individuals, moral hazard and the size of the banking sector. In section 2.5, we analyze the effect of different degrees of heterogeneity on the optimal level of minimum capital requirements. Section 2.6 concludes.

2.2 Model Setup

We follow Morrison and White (2005) with the basic setup of the model and consider a one period economy with a continuum of risk-neutral agents with mass 1, denoted by i.[5] All individuals are heterogeneous with respect to an unobservable ability a_i, $a_i \sim U(0,1)$.[6] We interpret this competence as different levels of efficiency in monitoring and project screening. Each agent is endowed with capital C.[7] She may use this amount for one of three different investment opportunities and she consumes the endowment plus returns at the end of the period. The three investment opportunities are as follows: First, she can run an investment project chosen from a whole set of projects, $y_i \in [0,1]$ with a risk-return structure à la Allen and Gale (2004), i.e., the success probability is decreasing in the return of the project, $\left(\frac{\partial p(y_i,a_i)}{\partial y_i} \leq 0\right)$.[8] We assume the success probability to be increasing in the unobservable ability of the agent $\left(\frac{\partial p(y_i,a_i)}{\partial a_i} \geq 0\right)$. Particularly, we take the functional form $p(y_i,a_i) = (1-y_i)a_i$. The investment pays a return $x \cdot y_i$ in case of

[5]In contrast to Morrison and White (2005), we consider a continuum of agents for the reason of computational convenience.

[6]In section 2.5, we abstract from the unit interval and analyze different degrees of heterogeneity by generalizing the uniform distribution. Note that the results of this chapter qualitatively do not depend on the distribution of a_i.

[7]Since the continuum of agents is normalized to mass 1, the total endowment in the economy is C.

[8]In order to rule out any hedging motives, we restrict individuals to choose only one investment project.

success and zero otherwise, where x is a constant scaling factor.[9] Thus, individuals with different abilities have different expected returns from investing into the risky projects.

The invested amount is not restricted to the own endowment, but agents are allowed to collect further funds from other agents. We call the agents collecting deposits banks. Thus, a second investment opportunity is to lend an amount D_i of the own endowment to other agents.[10] This lending pays an interest r per unit of D_i, which is completely determined by supply and demand. However, deposits can only be repaid if banks have enough cash flow, i.e., only in case of a successful completion of the project. We assume that depositors can verify banks' investment and returns, which prevents banks from mimicking being insolvent. We further assume a zero correlation structure regarding the return of two different investment projects, $corr(xy_i, xy_j) = 0, \forall i, j \in I$ in order to rule out any hedging motive for lending agents. Moreover, we make depositors to anticipate the moral hazard behavior of banks and to be able to price risks accordingly in the deposit rate.[11] The third investment opportunity is to store the endowment in a risk-free asset, which pays a gross interest rate $r_f = 1$.

We introduce a regulator as an additional agent who has the power to put a minimum capital adequacy on banks. In contrast to Morrison and White (2005), we restrict the toolbox to set minimum capital requirements since it represents the cornerstone of the Basel regulatory framework.[12] The regulator's adjustment screw implies a leverage ratio, which is defined as the ratio of equity capital C over total assets, $C + D_i$, i.e., $\frac{C}{C+D_i}$. Since C is fixed, she has to define the maximum amount of funds banks can raise from individuals, D^{max}.

The timing and sequence of events in the model are as follows: First, the regulator defines the minimum capital adequacy banks are required to hold. Second, individuals decide about the choice of investing into the risky project, depositing at a bank, or investing into the risk-free asset. If the risky project was selected, individuals decide simultaneously

[9] We assume x to be sufficiently large such that the expected return from investing into the risky project is high enough to ensure that not all agents will invest only into the risk-free asset. Assuming, e.g., $x = 8$ would ensure that half of the population has a non-negative NPV from investing only its endowment in the efficient project.

[10] We assume that investors are only willing to provide debt capital rather than additional equity which could arise in the short run due to a debt overhang problem.

[11] Note that with the existence of a deposit insurance, one could also interpret the banks' payments to depositors as the sum of payments to the depositors and a deposit insurance where depositors receive a fixed amount corresponding to the expected repayment without a deposit insurance.

[12] We abstract from the possibility to close a bank before returns are realized and predefining an exogenous number of banks, respectively. First, although a regulator might in principle have the power to close a bank, she will not do so before any misbehavior has occurred and she is hardly able to detect any malfunction ex ante. Second, a regulator does hardly limit licenses up to a particular number, but allows to open a bank when all obligations are fulfilled.

about becoming a bank, choose the volume of deposits they want to take, as well as the risk-return structure of the risky investment project. Finally, returns are realized and deposits are paid back.

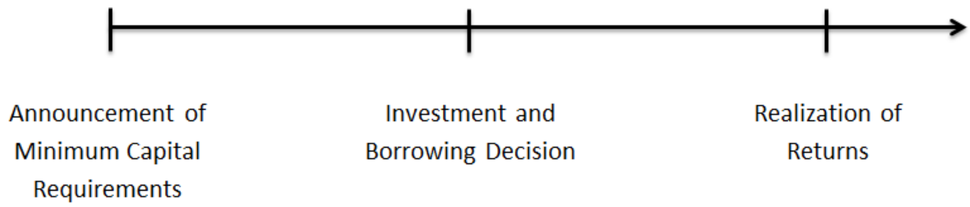


Figure 2.1: Timeline of the decision structure

2.3 Payoffs and Investment Choice

The expected profit of a bank that invests into the risky project consists of the return from the investment project and the costs from borrowing in the deposit market.[13] Thus, it is given by

$$E(\pi_i^{y_i}) = (C + D_i)(1 - y_i)a_i x y_i - (1 - y_i)a_i r D_i - C.$$

We assume that there will be no bailout of deposits so that individuals lending in the deposit market will only be repaid if the borrowing counterparts can generate enough positive cash flow, which is always the case when they succeed in the investment project. Thus, the individual's expected profit from lending his own endowment takes the expected ability of banks into account and reads

$$E(\pi_i^D) = \frac{1}{\int \mathbf{1}_{j^{bor}} dj} \int a_j(1 - y_j)\mathbf{1}_{j^{bor}} dj Cr - C,$$

where $\frac{1}{\int \mathbf{1}_{j^{bor}} dj} \int a_j(1 - y_j)\mathbf{1}_{j^{bor}} dj$ denotes the average expected success probability of the borrowing counterparts. Thus, $\frac{1}{\int \mathbf{1}_{j^{bor}} dj} \int a_j(1 - y_j)\mathbf{1}_{j^{bor}} dj Cr$ describes the expected repayment.

All individuals also have the option to invest their funding resources into a risk-free asset. Since the deposit rate has to exceed the risk-free rate, an individual will never borrow for this investment. This gives the expected profit

$$E(\pi_i^{RF}) = Cr_f - C = 0.$$

[13]We will later show that there exists only a pooling equilibrium in the deposit market. Therefore, in order to simplify notation, we will never use a subscript i for the interest rate.

In order to find the optimal investment decision as well as the optimal volume in the deposit market, agents solve the maximization problem

$$\begin{aligned}\max_{\alpha_i,\beta_i,D_i,y_i} E(\pi_i) &= \alpha_i \left\{(C+D_i)(1-y_i)a_i x y_i - (1-y_i)a_i r D_i - C\right\} \\ &+ \beta_i \left\{\frac{1}{\int \mathbf{1}_{j^{bor}} dj} \int a_j(1-y_j)\mathbf{1}_{j^{bor}} dj Cr - C\right\} \\ &+ (1-\alpha_i-\beta_i)\left\{Cr_f - C\right\} \qquad (2.1)\end{aligned}$$

s.t.

$$0 \leq \alpha_i + \beta_i \leq 1$$
$$D_i \leq D^{max}$$
$$y_i \in [0,1].$$

Note that, due to the linearity of the profit functions, agents will only choose one of the possible investment opportunities, i.e., they will either invest into the risky project, become a depositor, or invest into the risk-free asset.

An individual i will decide to invest into the risky project, i.e., $\alpha_i = 1$, if and only if

$$\frac{\partial E(\pi_i)}{\partial \alpha_i} > 0 \text{ and } \frac{\partial E(\pi_i)}{\partial \alpha_i} > \frac{\partial E(\pi_i)}{\partial \beta_i},$$

it will lend its endowment to a bank ($\beta_i = 1$) if and only if

$$\frac{\partial E(\pi_i)}{\partial \beta_i} > 0 \text{ and } \frac{\partial E(\pi_i)}{\partial \beta_i} > \frac{\partial E(\pi_i)}{\partial \alpha_i},$$

and it is indifferent between investing and lending if and only if

$$\frac{\partial E(\pi_i)}{\partial \alpha_i} = \frac{\partial E(\pi_i)}{\partial \beta_i} > 0.$$

If non of these conditions hold, agents will neither provide deposits, nor act with regard to an investment into the risky project, but only invest into the risk-free asset.

Given agents choose to finance a risky investment project, i.e., $\alpha_i = 1$, they face the decision whether or not they want to collect deposits and hence, become a bank as well as about the risk-return structure of the project.

Proposition 2.1. *All agents with $\alpha_i = 1$ choose, due to limited liability, an inefficient high project risk y_i^*, which is increasing in the leverage and the deposit rate.*

Proof. See Appendix 2.A.1. ■

Proposition 2.2. *All agents with $\alpha_i = 1$ want to, for a given deposit rate r, either take as much funds as possible, or they want to take no deposits.*

Proof. See Appendix 2.A.2. ■

It is important to note that, since we consider a continuum of banks, they do not have the market power to influence the interest rate on the deposit market and take it therefore as given.

One might think that the existence of a moral hazard problem results in an interior solution for the optimal amount of deposits for a sufficiently high value of D^{max}. The reason could be the deterioration of the expected return per unit invested for an increasing deposit volume, which could decrease expected profits large enough to incentivize banks not to collect as much deposits as possible. However, since banks take the deposit rate as given, the decline in expected return is not strong enough to outweigh the benefit from a larger investment volume.

Both the decision about the project choice and the decision about the optimal debt level do not depend on the agent's unobservable ability. All individuals for whom it is beneficial to choose the investment project will decide for the same project $y_i^* = y^*$, independent of a_i. Thus, since agents' ability affects the success probability, they have different expected returns from investing into the risky projects.

2.3.1 Allocation Effect

The intersection of both the expected return of the investment project and the expected return from depositing at a bank for various ability a_i, depicted in Figure 2.2, ensures that there exists a critical level of ability a^*, above which agents decide not to deposit their funds with a bank.[14] The remaining fraction of agents with ability $a_i \in [0, a^*[$ will either deposit their complete endowment with a bank or invest into the risk-free asset. Ignoring any participation constraint and assuming that no individual chooses to invest into the risk-free asset, all agents whose ability exceeds a^* will open a bank and all remaining agents deposit their funding resources with a bank. Thus, depositors and the regulator know the expected ability of banks to be $\frac{1}{2}(1 + a^*)$.

The market clearing condition for the deposit market allows us to identify the critical

[14] Technically, $\frac{\partial E(\pi_i^{y_i})}{\partial a_i} > 0$ and $\frac{\partial E(\pi_i^D)}{\partial a_i} = 0$ as well as $E(\pi_i^y | a_i = 0) < E(\pi^D | a_i = 0)$ ensures the intersection of both expected return functions.

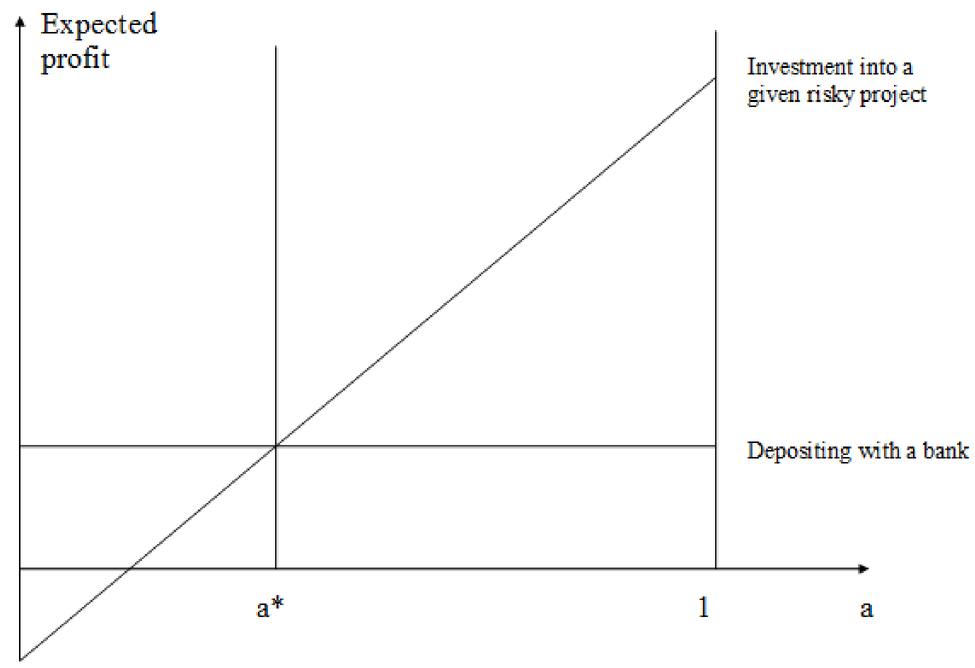


Figure 2.2: Expected profit for investing into a risky project or depositing at a bank for a given interest rate r, deposit volume D, and project return y_i.

ability a^*,

$$\int_0^{a^*} C di = \int_{a^*}^1 D^{max} di$$

$$\Leftrightarrow \qquad a^* = \frac{D^{max}}{C + D^{max}}. \tag{2.2}$$

Thus, the ability level, above which individuals decide to choose the risky investment project, depends positively on the regulatory maximum of depositor lending D^{max}.[15]

Equation (2.2) and Figure 2.2 provide an illustrative intuition of the selection problem we intend to highlight in our model. For a stricter regulation in the sense of higher capital requirements (decrease of D^{max}), the critical ability a^* decreases, implying that the banking sector might become less stable since the average ability of banks decreases.

2.3.2 Participation Constraints

So far, we have solved the individuals' maximization problem but neglected any participation constraints. Therefore, we will now implement the natural constraints the agents are facing in order to derive a necessary and sufficient condition for the existence of a debt market.

[15] $\frac{\partial a^*}{\partial D^{max}} = \frac{C}{(C+D^{max})^2} > 0.$

First, all individuals have the possibility to use only their own endowment for investing into the risky project. This outside option pays the expected profit

$$E(\pi_i^{O1}) = C(1-y_i)a_i x y_i - C,$$

being maximized for the project $y = \frac{1}{2}$.

Second, individuals are allowed to invest their initial endowment into the risk-free asset, which pays

$$E(\pi_i^{O2}) = Cr_f - C.$$

Thus, in order to set up the constraints for participating in the banking sector for both opening a bank or depositing funds with a bank, we compare the two outside options with the expected profit for individuals being a bank as well as with the expected profit for depositing initial funding resources.

Since all banks choose the maximum possible amount of deposits, $D_i = D^{max}$, and using the optimal project choice $y^* = \frac{1}{2} + \frac{rD^{max}}{2(C+D^{max})x}$, the expected profit for deposit taking and running a bank reads

$$E(\pi_i|y^*) = (C+D^{max})\left(\frac{1}{2}-\psi\right)a_i\left(\frac{1}{2}+\psi\right)x - \left(\frac{1}{2}-\psi\right)a_i r D^{max} - C$$

with $\psi = \frac{rD^{max}}{2(C+D^{max})x}$.

Thus, the participation constraints for agents to open a bank read

$$(C+D^{max})\left(\frac{1}{2}-\psi\right)a_i\left(\frac{1}{2}+\psi\right)x - \left(\frac{1}{2}-\psi\right)a_i r D^{max} - \frac{1}{4}Cxa_i \geq 0 \qquad \text{(BOR1)}$$

and

$$(C+D^{max})\left(\frac{1}{2}-\psi\right)a_i\left(\frac{1}{2}+\psi\right)x - \left(\frac{1}{2}-\psi\right)a_i r D^{max} - Cr_f \geq 0, \qquad \text{(BOR2)}$$

which, solving for r, give two boundaries for agents investing into the risky project to taking deposits, $r_1^{bor}(D^{max})$ and $r_2^{bor}(a_i, D^{max})$.[16]

Since the expected profit from banking is decreasing in r, banks are willing to demand additional funding resources in the deposit market if the equilibrium interest rate is below both boundaries. Note that the first boundary does not depend on a_i, implying that either no or all agents are willing to obtain deposits for investing into the risky investment project. However, the second boundary depends positively on a_i.[17] Economically, agents

[16] Both participation constraints are quadratic functions in r, so that there exist in both cases two interest rates that fulfill the constraints with equality. However, we can rule out those interest rates that would generate optimal projects $y_i \notin [0, 1]$.

[17] In the following, we will evaluate the second borrowing constraint (BOR2) always at the critical bank ability a^*. Since this constraint is increasing in a_i and a^* is the lowest ability level for borrowing banks, the minimum binding participation constraint (BOR2) can only be at a^*.

with a higher ability can expect a higher return from investing into the risky project and thus, funding costs have to be higher in order to incentivize those agents to invest into the risk-free asset instead of collecting deposits and opening a bank.

In contrast to the participation constraints for being a banker, which are independent from the ability of the depositors, the constraints for lending the endowment to a bank depend on the expected success probability of the depositing bank. Since the ability of bankers is not observable, depositors form expectations about their counterparts' ability[18] as well as their optimal project choice, taking into account that all banks choose the maximum amount of deposits, $D_i = D^{max}$. Thus, the participation constraints for depositors with respect to a risky investment of their endowment by their own and with respect to investing into the risk-free asset then read

$$\frac{1}{2}(1+a^*)\left(\frac{1}{2}-\psi\right)rC - \frac{1}{4}Cxa_i \geq 0 \tag{LEND1}$$

and

$$\frac{1}{2}(1+a^*)\left(\frac{1}{2}-\psi\right)rC - Cr_f \geq 0. \tag{LEND2}$$

Solving for r again delivers two boundaries for individuals to participate as a lender in the deposit market, $r_1^{lend}(a_i, D^{max})$ and $r_2^{lend}(a_i)$. In contrast to the negative relationship of expected profit and funding costs r for banks, the expected profit for depositors is increasing in r, so that depositing is incentive compatible if the equilibrium interest rate lies above both boundaries. Moreover, the effect of D^{max} on the participation constraints is ambiguous. First, the participation constraints depend positively on D^{max}, which arises since a^* is an increasing function in D. The intuition is that an increasing a^* ceteris paribus increases the average success probability of investing banks, hence increasing the expected payoff for depositors. Second, both constraints are negatively depending on the moral hazard effect, which is also increasing in D^{max}.

Again, one of the participation constraints, i.e., the decision to either deposit or invest into the risk-free asset, does not depend on the individuals' ability, implying that either all agents or no agent are willing to deposit their endowment rather than investing into the risk-free asset. In contrast, the participation constraint forming the decision about depositing or investing initial capital into a risky project depends positively on the individual abilities a_i. Obviously, since high-ability agents expect higher project returns than low-ability agents, they require a higher interest rate in order to offer additional funding resources in the form of deposits.[19]

[18] They use the expected value of the bankers' ability, $\frac{1}{2}(1+a^*)$.

[19] Similar as borrowing constraint (BOR2), we will evaluate the first lending constraint (LEND1) always at bank a^*. Since this constraint is decreasing in a_i and a^* is the highest ability level for depositors, the maximum binding participation constraint (LEND1) can only be at a^*.

We know that individuals want to lever up their equity for investing into the risky project and become a bank if the equilibrium interest rate lies below both boundaries for borrowing banks. We further know that there are individuals that are willing to lend if the equilibrium interest rate is above both boundary rates for depositing.

Proposition 2.3. *There exists a deposit market if and only if* $r_{1i}^{bor} \geq r^{eq} \geq r_{1j}^{lend}$ *and* $r_{2i}^{bor} \geq r^{eq} \geq r_{2j}^{lend}$ *are satisfied for at least some individuals* $i, j \in I$ *with ability* $a_i \neq a_j$ *.*

Proof. See Appendix 2.A.3. ■

2.4 Equilibrium

Taking the participation constraints into account, we now characterize the equilibrium outcome where either all funds of the economy will be invested into the investment project or a part of the endowments will be tied up in the risk-free asset. Since the deposit market is at the heart of our model, any assumption regarding its mechanism is essential. We suppose that all participating individuals enter the market at the same time, and the matching of banks and depositors is purely random. Note that depositing agents are indifferent between lending to as few banks as possible or to fully diversify their deposits. This is caused by the risk neutrality of individuals, the identical expected ability of the bankers, and the zero correlation between returns of the projects of banks. For the same reason, we can exclude bargaining power for any agent.

In the previous section, we have identified situations in which a deposit market exists. Since we are interested in the effect of changes in the minimum capital requirements on banks' behavior, we first concentrate the analysis on the case in which the capital regulation is binding in the sense that banks want to, but are not allowed to take further deposits.[20] For binding capital regulation we claim that there exists only a pooling equilibrium in the deposit market.

Proposition 2.4. *There exists a pooling equilibrium in the deposit market in the sense that every bank gets the same expected volume of deposits* D^{max} *at the same market clearing interest rate* r^{eq}*.*

Proof. See Appendix 2.A.4. ■

We define the pooling equilibrium in the following definition:

[20]The case of an unconstrained equilibrium is analyzed in Proposition 2.8.

Definition 2.1. *A pooling equilibrium is a set of allocations* $\{D_i, y_i, \alpha_i, \beta_i\}, i \in [0,1], y_i \in [0,1]$ *and a deposit market interest rate* r^{eq}*, such that*

- *given the deposit rate, the allocation solves each agent's maximization problem*
- *the deposit market clears.*

Proposition 2.5. *There exists no separating equilibrium, in which banks with different abilities* a_i *prefer different contracts, i.e., contracts specifying different deposit rates and volumes.*

Proof. See Appendix 2.A.5. ■

The intuition why there exists only a pooling equilibrium is straightforward. First, the individual ability a_i is not observable. Second, the relevant participation constraint for running a bank, BOR1, is independent of a_i, which in addition is just a scaling factor for the expected profit from investing into the risky project. Hence, if the borrowing banks have the choice between two or more contracts, different banks always prefer the same contract. Finally, depositors can not distinguish between different abilities of bankers in order to claim ability-dependent deposit rates.

However, the pooling equilibrium differs for various levels of capital regulation with respect to the fund volume invested in the risky project. If the regulator demands a very high leverage ratio, the expected profit of the investment project does not exceed the expected profit from the risk-free asset for some agents. Thus, some part of the endowment of the economy will not be invested in investment projects. Note that depositing those funds is not possible due to the regulatory constraint. We call this situation limited participation equilibrium.

2.4.1 Limited Participation Equilibrium

The limited participation equilibrium is characterized by a situation in which demand and supply of funding resources can not be equalized by an equilibrium interest rate that fulfills the participation constraints of all individuals. For very strict capital requirements, some agents with a too low success probability can only generate a low expected return from the investment project and thus prefer not to switch to become a bank (see Figure 2.3). However, since BOR2 is increasing in the ability level, there are still individuals with $a_i > a^*$ for which their individual participation constraint BOR2 is above LEND2 evaluated at a^*. The excess supply of funds drives down the equilibrium interest rate to $r^{eq} = r_2^{lend}$

due to a Bertrand price competition argument and will rather be invested into the risk-free asset instead of the investment project. Hence, as in Morrison and White (2005), the adverse selection problem and the moral hazard problem can be solved simultaneously for very strict capital requirements, but it comes at the cost of an inefficiently high investment volume into the risk-free asset. Moreover, note that the limited participation equilibrium exists only due to the assumption of the additional outside option to invest into the risk-free asset. It would disappear if we drop this investment opportunity, as it is done in Morrison and White (2005). Note further that limited participation does not necessarily require some individuals not to participate in the banking sector, but only that not all agents can deposit their complete funding resources.

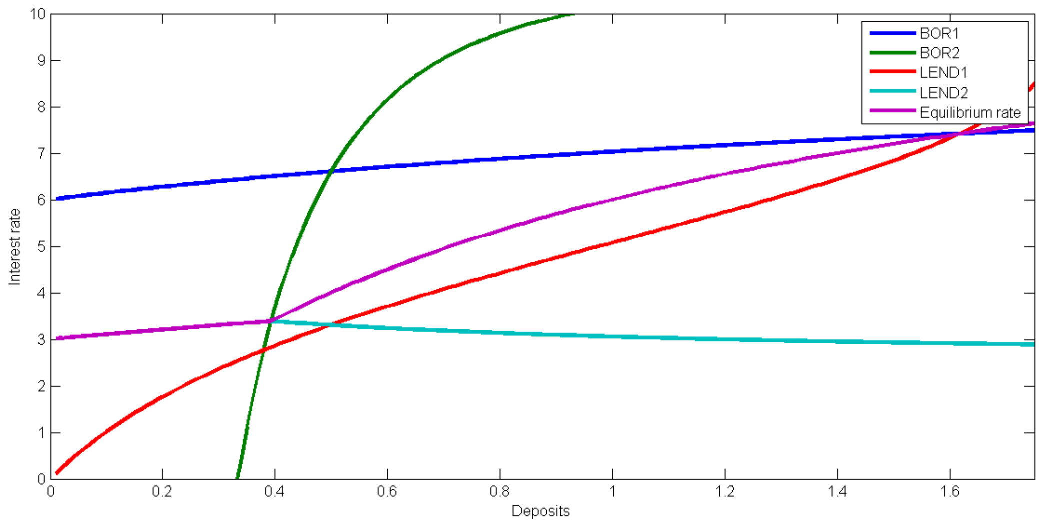


Figure 2.3: Participation constraints and equilibrium interest rate for parameter values $x = 12$ and $C = 1$.

2.4.2 Full Participation Equilibrium

For any regulatory capital requirement below the very strict ones that result in the limited participation equilibrium, all funding resources of the economy are invested in the risky project. We claim the existence of the full participation equilibrium in the following proposition:

Proposition 2.6. *For x sufficiently large, there exists a full participation equilibrium in the sense that all agents participate by either running a bank or depositing their endowment with a bank.*

Proof. See Appendix 2.A.6. ■

Proposition 2.7. *The allocation that solves the problem is given by:*

- $\forall\ i$ *with* $a_i \in \left[0, \frac{D^{max}}{C+D^{max}}\right[$*:* $D_i = 0, \alpha_i = 0, \beta_i = 1$
- $\forall\ i$ *with* $a_i \in \left[\frac{D^{max}}{C+D^{max}}, 1\right]$*:* $D_i = D^{max}, y_i = \frac{1}{2} + \frac{rD^{max}}{2(C+D^{max})x}, \alpha_i = 1, \beta_i = 0.$

The equilibrium interest rate is given by $r^{eq} = \frac{D^{max}x}{(C+D^{max})}$*.*

Proof. See Appendix 2.A.7. ■

The intuition for the full participation equilibrium interest rate is as follows. Remember that there exists a certain ability level $a^* = \frac{D^{max}}{C+D^{max}}$ for which individuals with a higher ability want to take as many deposits as possible and invest into the risky project and individuals with a lower ability will act as depositors. Remember further that there exists an equilibrium deposit market interest rate that is below the borrowing constraints for all agents with ability above a^* and above the lending constraints for all agents with ability below a^*. Since the equilibrium interest rate serves as a market clearing price, individuals with exact the critical ability level a^* must be just indifferent between opening a bank and depositing. We illustrate the equilibrium interest rate for different levels of D^{max} in Figure 2.3.

Note that so far, we have analyzed the case in which the minimum capital requirements are binding. However, there also exists an unconstrained equilibrium for high values of the maximum level of deposits D^{max}.

Proposition 2.8. *There exists an unconstrained equilibrium with* D_{uc}^{max} *defined by the intersection of* $r_1^{bor}(D_{uc}^{max})$ *and* $r_1^{lend}(D_{uc}^{max}, a_i|a_i = a^*)$*.*

Proof. See Appendix 2.A.8. ■

Intuitively, the existence of the unconstrained equilibrium stems from the following effect: For high values of D^{max}, the agent that is indifferent between lending and borrowing has a high ability a_i. This individual requires a high interest rate in order to offer its endowment as deposits. However, this high payment on debt decreases the expected profit for banks and incentivizes them to invest only equity into the investment project. Hence, having an endogenous price for deposits, there exists a natural boundary for deposit taking although the regulator would allow a higher leverage.

2.4.3 Comparative Statics

After having developed the equilibrium for different levels of capital regulation, we will now analyze in more detail the role of the deposit market and the effects emanating with respect to regulation.

Formally, we define the allocation effect stemming from the selection problem as the difference between the average ability of the pool of banks and the average ability of all individuals:

$$AE = \frac{1}{2}(1 + a^*) - \frac{1}{2} = \frac{D^{max}}{2(C + D^{max})}.$$

Thus, a stricter regulation leads to a decline in a^*, implying that some agents with a lower success probability decide to become a bank instead of being a depositor. Hence, ceteris paribus, a stricter regulation decreases the average success probability of banks.

It is convenient to define the moral hazard effect in our model as the exceedance of the project risk over the efficient project,

$$MHE = \frac{rD^{max}}{2(C + D^{max})x}.$$

Decomposing the effect of a stricter regulation on the moral hazard effect demonstrates the second effect imposed by the deposit market on banks' risk-taking.

$$\frac{\partial MHE}{\partial D^{max}} = \frac{rC}{2(C + D^{max})^2 x} + \underbrace{\frac{\frac{\partial r}{\partial D^{max}} D^{max}}{2(C + D^{max})x}}_{\substack{\text{Change of moral hazard effect} \\ \text{due to deposit market interest rate}}} > 0.$$

Since a stricter regulation decreases the demand for deposits, some individuals have to switch from depositing to being a bank, which, ceteris paribus, decreases the average success probability in the pool of depositors. Since the 'best' agent in the pool of depositors has now a lower success probability and hence a lower expected return from its outside option to run a bank, depositors are now willing to offer their funding resources at a lower interest rate, which implies a reduction of the moral hazard effect.[21] Therefore, this second effect is countervailing to the allocation effect and mitigates the negative impact of moral hazard behavior on the aggregate payoff in the economy.

Note that the remaining reaction of the moral hazard effect on a stricter regulation is due to the classical problem of limited liability. If the regulator strengthens regulation by

[21] See Appendix 2.B for a analytical derivation of the dependence between the equilibrium interest rate and D^{max}.

demanding a larger share of equity (decrease in D^{max}), banks choose less risky projects since they have more 'skin in the game'.

Thus, the regulatory austerity leads first to a worsening of the pool of banks, increasing the selection problem. Second, a lower deposit rate decreases the moral hazard problem in addition to its reduction through a lower leverage.

The first result we want to highlight is the fact that changes in capital requirements in the region of full participation do not affect the volume of managed funds in the banking sector. One concern of Morrison and White (2005) with regard to tighter capital requirements is a welfare mitigating decrease of the whole banking sector. However, endogenizing the deposit market interest rate and reducing the instruments of the regulator to minimum capital requirements implies that the deposit market takes the role of controlling the number of banks and the volume of managed funds in the banking sector. It appears that the number of banks and the size of the banking sector are disentangled. This is one of the key differences to the model of Morrison and White (2005), where the number of banks is fixed by the number of licenses and hence, stricter capital requirements directly decrease the volume of managed funds. Moreover, the introduction of a deposit rate that equalizes demand and supply implies that the selection problem is controlled by the deposit market. It incentivizes agents with a low ability to deposit their funds with a bank and high-ability agents to open a bank. However, a regulatory change in terms of stricter capital requirements affect the average success probability of the pool of banks in three different ways. First, a stricter regulation has an immediate effect on the banks' project choice. Since banks have 'more skin in the game', their incentive to take excessive risks diminishes. Second, the average ability of the pool of banks gets worse. Low ability agents decide to open a bank which increases the number of banks, but decreases the average success probability of all investing agents and thus, ceteris paribus, the expected return to depositors. The third effect of stricter regulation again affects the moral hazard behavior of banks. After some agents changed from being a depositor to being a bank, the remaining supply side of debt has a lower ability and thus accepts a lower deposit rate. This lower debt rate translates into a decline of the optimal project risk chosen by banks. Hence, our result of a countervailing moral hazard and selection problem with a constant volume of bank-financed investment projects is contrary to the findings of Morrison and White (2005).

Our second result shows that the effects of stricter capital requirements in a situation of limited participation are different to the full participation case. In such a situation, the effect of higher capital requirements on the selection problem has the opposite direction and hence, works in the same course as the moral hazard effect. Since banks are forced to reduce their total assets, they require a higher margin to run the bank. Since banks with a low ability cannot generate this margin, they will drop out of the market. Thus, after a regulatory austerity, the banking sector has a higher average ability. However, the size of the banking sector and hence, the amount that is invested into the risky project decreases. In some sense, these results are similar to the findings of Morrison and White (2005), but note that the limited participation case only occurs because we introduce the risk-free asset as an additional investment opportunity.

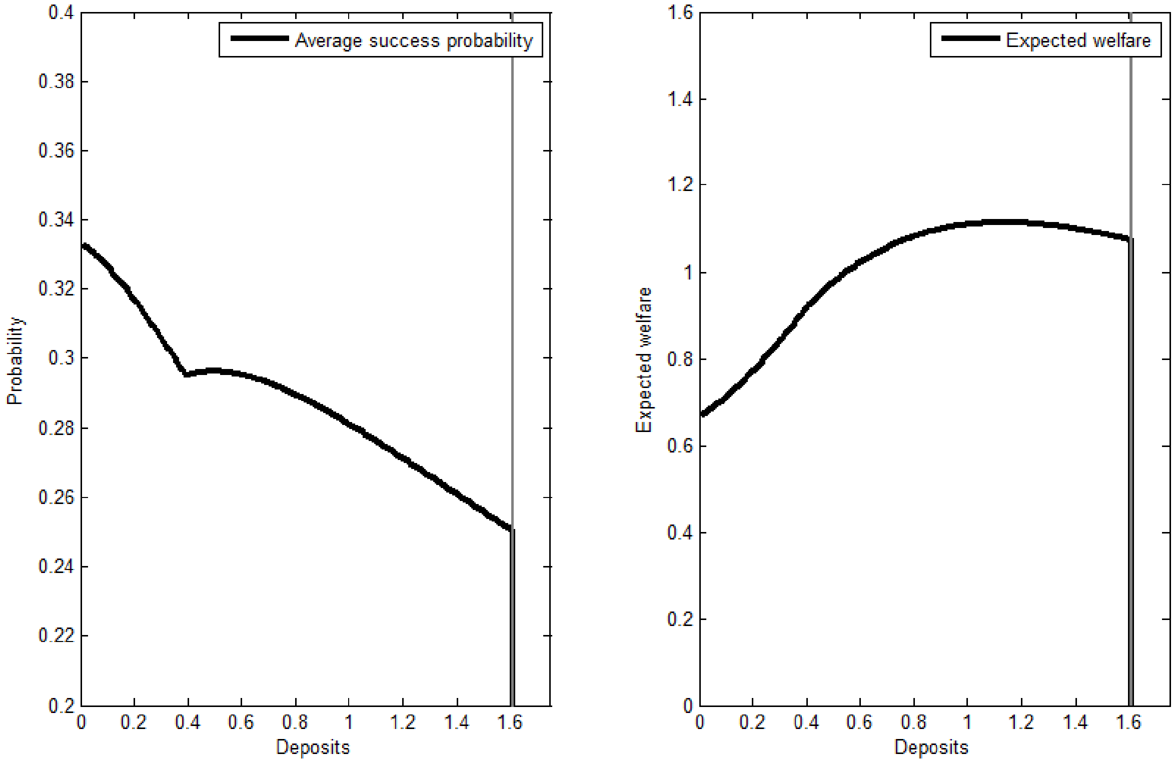


Figure 2.4: Average success probability and Aggregated expected profits for parameter values $x = 12$ and $C = 1$.

Figure 2.4 shows the average success probability of the risky investment and the expected total profits in the economy. In the limited participation case, the average success probability is decreasing in the deposit volume, since both the selection and the moral hazard problem get more pronounced. However, in the area of full participation, where the selection and the moral hazard problem are countervailing, the concavity of the average success probability demonstrates that the sensitivity of the allocation effect with respect to D^{max} may be relatively strong for higher levels of capital requirements, but may be outweighed by the sensitivity of the moral hazard effect for a looser regulation.[22] The intuition is that for high values of D^{max} only some agents become a bank and borrow in

[22]Note, that the relative strength of both effects depends on the choice of the parameter values.

the deposit market in order to invest into the risky asset. If the regulation gets looser, these few banks increase demand in the deposit market only by a small amount. Hence, only a small number of agents switches from being a depositor to being a bank, which translates into a small change of the allocation effect.

The implementation of a tighter capital regulation has heterogeneous effects on agent's riskiness if we consider a full participation equilibrium. Note that the decision about the risk-return structure implies a differentiated picture. First, those agents for whom it was optimal to be a bank already before the regulatory reform are only prone to the moral hazard effect. Since a stricter regulation incentivizes these banks to choose less risky projects, their riskiness unambiguously decreases.

Second, those agents who have been depositors before the reform, but now switch to collect deposits and invest into the risky project are affected by both the allocation and the moral hazard effect. They replace their counterparty risk from lending their endowment to a bank by their individual project risk. On the one hand, the pool of banks ceteris paribus has a lower average success probability than the former pool. On the other hand, all banks choose less risky projects. Hence, for this group, the effect of a stricter regulation on the riskiness is ambiguous.

Finally, agents still lending in the deposit market face an ambiguous effect regarding the riskiness of their portfolio. Banks choose less risky projects, but the pool of banks gets worse. Thus, this group of agents is prone to a mitigation of the moral hazard problem and a worsening of the allocation of funding resources, too. The relative impact of the two effects depends on the level of regulation, D^{max}.

Note that, although the group of agents which have been banks before and after the reform is not affected by the allocation effect, this group's relationship between regulation and risk-taking is also influenced by the deposit market since they choose the riskiness of their projects partly according to the deposit market interest rate. Tighter capital requirements decrease the deposit rate, which motivates banks to finance less risky projects.

In the limited participation equilibrium, we have a decline in risk-taking for all banks, since a stricter capital regulation decreases the moral hazard effect and increases the allocation effect. Intuitively, banks choose less risky projects and the pool of banks gets better. Therefore, the quality of lending agents' portfolios of deposits unambiguously improves.

2.5 Degree of Heterogeneity

In this chapter, we analyze the effect of different degrees of heterogeneity on the optimal level of minimum capital requirements. For this purpose, we will weaken the assumption that the individual ability is distributed on a unit interval and introduce a mean preserving spread as a more general notation.[23] More precisely, all agents are different with respect to an unobservable ability a_i, $a_i \sim U(\underline{a}, \overline{a})$, but the mean of the distribution is still assumed to be $a^{mean} = 0.5$. We define $\Delta_a = \overline{a} - \underline{a}$ as the degree of heterogeneity. Note that the representation of the payoffs and the investment choices of section 2.3 still apply.

As in section 2.3.1, there exists a critical ability a^*, below which agents will either deposit their endowment at a bank or invest into the risk-free asset. The remaining fraction of agents with ability $a_i \in [a^*, \overline{a}]$ will decide in favor of the investment project. Thus, depositors as well as the regulator know the expected ability of banks to be $\frac{1}{2}(a^* + \overline{a})$. Using the market clearing condition for the deposit market, we find the critical ability for any level of heterogeneity

$$a^* = \frac{\underline{a}C + \overline{a}D^{max}}{C + D^{max}}.$$

Thus, the critical ability depends positively on the regulatory maximum of deposit borrowing, D^{max}, and the strength of the effect is increasing in the degree of heterogeneity.[24]

The three effects of stricter regulation, derived in section 2.4.3, differ in their reliance on the degree of heterogeneity. First, the direct moral hazard effect resulting from banks having 'more skin in the game' does not depend on the overall distribution of the ability level. In the maximization problem, banks make their decision regarding the investment project only based on their own ability.

Second, the selection effect does depend directly on the heterogeneity of the banking sector. Due to the mean preserving spread, the average ability of banks has changed, while the average ability of all individuals remains constant. With the lower bound $\underline{a}$ and the upper bound $\overline{a}$ of the distribution of the ability, the allocation effect reads

$$AE = \frac{(2\overline{a} - 1)D^{max}}{2(C + D^{max})}.$$

Similar to section 2.4.3, stricter regulation implies a decline in the critical ability. Thus, agents with a lower success probability decide to become a bank instead of lending their endowment to better agents. Hence, ceteris paribus, a stricter regulation decreases the

[23] In order to focus only on the heterogeneity of ability in terms of variance, we fix the mean of the distribution at the same level as in the previous chapters. We thus keep the results comparable and avoid a level effect introduced by differences in the mean. For the reason of simplicity, we still assume a uniform distribution.

[24] $\frac{\partial a^*}{\partial D^{max}} = \frac{\Delta_a C}{C + D^{max}} > 0$.

success probability of banks. However, the strength of the allocation effect depends on the degree of heterogeneity. More precisely, the change of the allocation effect originating from a stricter regulation is the stronger the higher the degree of heterogeneity. The economic intuition is straightforward. The loss in average ability of banks through a stricter regulation gets stronger with a larger dispersion in the individuals' ability.

Finally, the additional moral hazard effect though the equilibrium interest rate on debt is also shown to be sensitive to the heterogeneity of agents' ability, since it affects the level of the critical ability a^*. With a more general degree of heterogeneity, the equilibrium interest rate reads $r^{eq} = \frac{\overline{a}(D^{max}-C)+C}{(C+\overline{a}D^{max})}x$. This interest rate on debt is still decreasing in the stringency of regulation, which, ceteris paribus, increases the success probability of banks. The strength of this effect is increasing in the degree of heterogeneity. Moreover, the interest rate declines in the dispersion of the agents' ability.[25] Intuitively, this result stems from the fact that the average ability of those agents who decide to become a bank unambiguously increases with increasing heterogeneity. Hence, due to the increase in the average success probability of banks, depositors accept a lower compensation rate for the riskiness of their deposits.

Analytically, the moral hazard effect can be expressed in the more general case as

$$MHE = \frac{D^{max}(\overline{a}(D^{max} - C) + C)}{2(C + \overline{a}D^{max})(C + D^{max})}.$$

It is increasing in the level of debt, and this increase depends on the degree of heterogeneity as well as the ratio $\frac{C}{D^{max}}$.

A natural objective for the regulator is the maximization of expected aggregated profits in the economy,

$$\begin{aligned} AP &= \frac{1}{\overline{a} - \underline{a}} \int_{a^*}^{\overline{a}} [(C + D^{max})(1 - y)a_i yx - (1 - y)a_i r D^{max}] \, da_i - C \\ &= \frac{\overline{a} - a^*}{\overline{a} - \underline{a}} \left[(C + D^{max})\frac{1}{2}(\overline{a} + a^*)(1 - y)yx - \frac{1}{2}(\overline{a} + a^*)(1 - y)rD^{max} \right] - C. \end{aligned}$$

In our model, expected profits are entirely generated by banks and then distributed among all individuals via the deposit market. Since the characteristic polynomial for the optimal regulatory maximum amount of deposits is of degree 5 and there does not exist a general analytical solution, we have solved the problem numerically, illustrated in Figure 2.5 for a maximum ability $\overline{a} \in]0.5, 1]$.[26] Not surprisingly, the optimal regulation for a decrease in the degree of heterogeneity approaches towards $D^{max} = 0$. In the extreme case where all agents have the same success probability, they would be indifferent between

[25] $\frac{\partial r^{eq}}{\partial D^{max}} = \frac{\overline{a}^2 C}{(C+\overline{a}D^{max})^2}x > 0$, $\frac{\partial^2 r^{eq}}{\partial D \partial \overline{a}} = \frac{2\overline{a}C^2}{(C+\overline{a}D^{max})^3}x > 0$, and $\frac{\partial r^{eq}}{\partial \overline{a}} = -\frac{C^2 x}{(C+\overline{a}D^{max})^2} < 0$.

[26] See Appendix 2.D for a derivation of the characteristic polynomial.

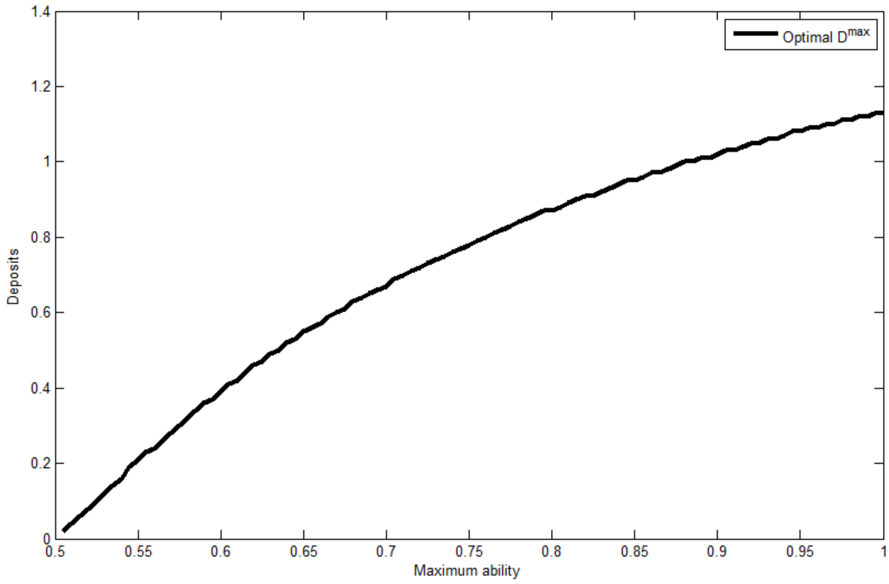


Figure 2.5: Optimal regulatory maximum amount of deposits D^{max} for parameter values $x = 12$ and $C = 1$.

investing and lending, and since there would be no market for deposits, there would be no moral hazard behavior. For increasing heterogeneity, however, Figure 2.5 indicates that optimal regulation should allow debt financing up to a certain degree. Moreover, the optimal level of debt is increasing in the degree of heterogeneity. Economically, differences in the quality of lending decisions imply positive effects of specialization. High-ability agents can generate the highest expected payoff from investment projects and depositors can benefit from that by providing funding to them. However, debt financed investment projects imply a moral hazard behavior that undermines the positive effects of specialization.

2.6 Conclusion

This chapter has analyzed the impact of a simultaneous problem of moral hazard and selection among individuals on the relationship between banking regulation and bank risk. To this end, we modify the model of Morrison and White (2005) by endogenizing the deposit market interest rate and restricting the regulator's responsibility to the policy of a minimum capital adequacy. We remove the task to predefine exogenously a fixed number of banks and to exert auditing in terms of closing a bank before any return has realized. To our view, both additional tasks in Morrison and White (2005) hardly reflect a realistic representation of banking regulation. First, there is no fixed number of banking institutes, but a bank license is granted to any applicant who is able to meet all relevant requirements. Second, a regulator is hardly able to know project returns before those projects mature and she can merely close a bank just because of its predictions.

We argue in a general equilibrium framework that, contrary to Morrison and White (2005), a stricter regulation does not necessarily lead to a more stable banking system. An economy where banks are heterogeneous with respect to a project success probability may suffer from a simultaneous moral hazard and selection problem when banks are forced to increase their leverage ratio. In particular, there are three effects arising from a stricter regulation. First, the moral hazard problem weakens since banks have more 'skin in the game'. Due to a diminished problem of limited liability, banks choose less risky investment projects. Second, there is a countervailing problem of selection among individuals. Banks are not allowed to absorb the excess supply of debt funding when a regulator demands a larger capital adequacy and additional equity cannot be raised. Therefore, some agents with a lower success probability start doing bank business such that the average quality of the banking sector deteriorates. This allocation effect, however, leads to a decline in the interest rate for debt which again mitigates the moral hazard problem. Thus, the overall effect of stricter banking regulation remains ambiguous.

In terms of risk exposure, the effect of stricter capital requirements is heterogeneous across agents. On the one hand, those agents with a high success probability are not affected by the allocation effect and thus, reduce project risk. On the other hand, the change in the regulatory framework incentivizes agents with a lower ability to engage in risky projects instead of lending in the deposit market. This behavior might increase their own risk exposure, which then spills over to the portfolio of depositors.

We further show that the effect of regulatory changes differ in the degree of heterogeneity. While the reduction of moral hazard due to 'more skin in the game' is independent of the distribution of agents' ability in the economy, both the selection problem as well as the moral hazard channel due to the price of debt do vary for an altering degree of heterogeneity. While stricter regulation exacerbate the problem of selection among individuals the more the larger the degree of heterogeneity, it also lowers the interest rate on debt to a larger extent if the difference between the highest and lowest ability agent increase.

We provide a theoretical framework showing a novel aspect of how stricter capital regulation might translate into a riskier banking system. Therefore, the new regulatory framework should have in mind that a stricter capital regulation potentially mitigates banks' malfunction due to moral hazard, but it might also have countervailing effects of either an increased project failure due to a lower quality in the banking system or a too small banking sector. These should especially be taken into account when there are large differences in banks' ability due to, e.g., specialization.

Appendix

2.A Proofs

2.A.1 Proof of Proposition 2.1

Since $\alpha_i = 1$, the expected profit is given by

$$E(\pi_i) = (C + D_i)(1 - y_i)a_i x y_i - (1 - y_i)a_i r D_i - C.$$

The first-order condition with respect to the risk-return structure yields

$$\frac{\partial E(\pi_i)}{\partial y_i} \stackrel{!}{=} 0$$

$$\Leftrightarrow \qquad y_i^*(D_i, r) = \frac{1}{2} + \frac{rD_i}{2(C + D_i)x},$$

with $\frac{1}{2}$ being the efficient project, and the second term indicating a moral hazard effect due to limited liability. Obviously, the project risk increases in the moral hazard effect. This distortion from the efficient project depends not only on the level of deposits D_i, but also on the deposit rate r (see Appendix 2.C).

2.A.2 Proof of Proposition 2.2

Since $\alpha_i = 1$, the expected profit is given by

$$E(\pi_i) = (C + D_i)(1 - y_i)a_i x y_i - (1 - y_i)a_i r D_i - C.$$

Plugging in for the optimal project choice y_i^* gives

$$E(\pi_i^{y_i}) = (C + D_i)\left(\frac{1}{4} - \frac{r^2 D_i^2}{4(C + D_i)^2 x^2}\right) a_i x - \left(\frac{1}{2} - \frac{rD_i}{2(C + D_i)x}\right) a_i r D_i - C.$$

Differentiating w.r.t. D_i:

$$\begin{aligned}\frac{\partial E(\pi_i^{y_i})}{\partial D_i} &= a_i x \left(\frac{1}{4} - \frac{r^2 D_i^2}{4(C+D_i)^2 x^2} - (C+D_i)\frac{\partial \frac{r^2 D_i^2}{4(C+D_i)^2 x^2}}{\partial D_i}\right) - a_i r \left(\frac{1}{2} - \frac{rD_i}{2(C+D_i)x} - D_i \frac{\partial \frac{rD_i}{2(C+D_i)x}}{\partial D_i}\right) \\ &= a_i \left(\frac{(C+D_i)^2 x^2 - r^2 D_i^2 - 2r^2 D_i C - 2(C+D_i)^2 xr + 2(C+D_i) r^2 D_i + 2r^2 D_i C}{4(C+D_i)^2 x}\right) \\ &= \frac{(C+D_i)^2 x(x-2r) + r^2(D_i^2 + 2CD_i)}{4(C+D_i)^2 x}.\end{aligned}$$

Case 1 ($x > \frac{2C+D_i}{C+D_i} r$): $\frac{\partial E(\pi_i^{y_i})}{\partial D_i} > 0$.

Case 2 ($x = \frac{2C+D_i}{C+D_i} r$): $\frac{\partial E(\pi_i^{y_i})}{\partial D_i} = 0$.

$$\begin{aligned}\frac{\partial^2 E(\pi_i^{y_i})}{\partial D_i^2} &= \frac{r^2(2D_i + 2C)4(C+D_i)^2)x - 8(C+D_i)xr^2(D_i^2 + 2CD_i)}{16(C+D_i)^4 x^2} \\ &= \frac{r^2 C^2}{2(C+D_i)^3 x} > 0.\end{aligned}$$

Note, that the first derivative has a root for some positive D_i. Since the second derivative is strictly positive, it indicates that we have a (global) minimum. Hence, we have a corner solution such that for $x = \frac{2C+D_i}{C+D_i} r$, the agent takes either deposits $D_i = D^{max}$ or $D_i = 0$.

Case 3 ($x < \frac{2C+D_i}{C+D_i} r$): $\frac{\partial E(\pi_i^{y_i})}{\partial D_i} < 0$.

2.A.3 Proof of Proposition 2.3

$\boxed{\Rightarrow}$ If a deposit market exists, there must be at least one agent depositing and one agent borrowing at some equilibrium interest rate. According to the participation constraints for banking, we know that $\forall r^{eq}$ with $r^{eq} \leq r_1^{bor}(D_i|D_i = D^{max})$ and $r^{eq} \leq r_2^{bor}(a_i, D_i|D_i = D^{max})$, banks want to borrow in the deposit market D^{max} and invest $(C + D^{max})$ into the risky project instead of investing only C into the risky project or the risk-free asset. According to the participation constraints of lending agents, we know that $\forall r^{eq}$ with $r^{eq} \geq r_1^{lend}(a_j, D_j|D_j = D^{max})$ and $r^{eq} \geq r_2^{lend}(D_j|D_j = D^{max})$, agents want to deposit the volume C with a bank instead of investing C into the risky project or the risk-free asset. Hence, $r_{1i}^{bor}(D_i|D_i = D^{max}) \geq r^{eq} \geq r_{1j}^{lend}(a_j, D_j|D_j = D^{max})$ and $r_{2i}^{bor}(a_i, D_i|D_i = D^{max}) \geq r^{eq} \geq r_{2j}^{lend}(D_j|D_j = D^{max})$.

$\boxed{\Leftarrow}$ by contradiction. Assume $\nexists$ deposit market. Then there is

(i) either no demand for deposits, i.e., $\forall i \in I$, either $r^{eq} > r_1^{bor}(D_i|D_i = D^{max})$ or $r^{eq} > r_2^{bor}(a_i, D_i|D_i = D^{max})$,

(ii) or no supply of deposits, i.e., $\forall j \in I$, either $r_1^{lend}(a_j, D_j | D_j = D^{max}) > r^{eq}$ or $r_2^{lend}(D_j | D_j = D^{max}) > r^{eq}$,

(iii) or both.

2.A.4 Proof of Proposition 2.4

Denote the maximum regulatory credit volume by D^{max}. Consider a situation in which all agents with an ability $a_i \geq a^*(D^{max})$ borrow D^{max} at the same interest rate r^{eq}. We know from the participation constraints that banks have no incentive to demand a lower deposit volume. Obviously, they also have no incentive to offer a higher interest rate.

Suppose some bank $i \in I$ only accepts an interest rate $r < r^{eq}$. Since r^{eq} makes the agent with ability $a^*(D^{max})$ indifferent between depositing and borrowing in the deposit market, agent $(a^*(D^{max}) - \epsilon)$ can be incentivized by an interest rate $r < (r^{eq} - \nu) < r^{eq}$ to switch from depositing to borrowing. Hence, it is beneficial for depositors of bank i to deposit at bank $(a^*(D^{max}) - \epsilon)$ the volume D^{max} with an interest rate $(r^{eq} - \nu)$. Since both investing C or depositing C is less worth for agent $i \in I$ than borrowing D^{max} and investing $(C + D^{max})$ at interest rate r^{eq}, she has no incentive to deviate.

Suppose some lending agent $j \in I$ only accepts an interest rate $r > r^{eq}$. Since there exists some agent $(a^*(D^{max}) + \epsilon)$, which can be incentivized to switch from borrowing to depositing for an interest rate $(r^{eq} + \nu)$, $r^{eq} < (r^{eq} + \nu) < r$, it is beneficial for the borrowing partner of agent $j \in I$ to borrow at agent $(a^*(D^{max}) + \epsilon)$ the volume D^{max} at the interest rate $(r^{eq} + \nu)$. Since investing C or borrowing D^{max} and investing $(C + D^{max})$ are less worth than depositing C at interest rate r^{eq}, agent $j \in I$ has no incentive to deviate. Offering a lower interest rate $r < r^{eq}$ or supplying a lower volume than C is never beneficial. Hence, also depositing agents have no incentive to deviate.

2.A.5 Proof of Proposition 2.5

Suppose two different contracts (r_1, D_1) and (r_2, D_2) with $D_1, D_2 \leq D^{max}$, so that we have for each bank $i \in I$:

$$(C + D_1)a_i y - a_i r_1 D_1 - C \geq (C + D_2)a_i y - a_i r_2 D_2 - C$$

or

$$(C + D_1)a_i y - a_i r_1 D_1 - C \leq (C + D_2)a_i y - a_i r_2 D_2 - C.$$

None of these inequalities do depend on a_i. Hence, all borrowing banks prefer the same contract.

2.A.6 Proof of Proposition 2.6

In order to have a full participation equilibrium, it is required that the participation constraints of all agents are fulfilled. We show that there exists some area where the binding constraint for borrowing agents lies above the binding constraint for lending agents.
Claim: For some D, the binding constraint for borrowing agents is (BOR1).

$$\begin{aligned} & \text{(BOR2)} > \text{(BOR1)} \\ \Leftrightarrow \quad & \frac{1}{4}Cxa^* > Cr_f \\ \Leftrightarrow \quad & D > \frac{4C}{x-4}. \end{aligned}$$

Note that we use the lower bound of (BOR1) with $a_i = a^*$.

Claim: For some D, the binding constraint for lending agents is (LEND1).

$$\begin{aligned} & \text{(LEND1)} > \text{(LEND2)} \\ \Leftrightarrow \quad & \frac{1}{4}Cxa^* > Cr_f \\ \Leftrightarrow \quad & D > \frac{4C}{x-4}. \end{aligned}$$

Note that we use the upper bound of (LEND1) with $a_i = a^*$.

Claim: For some D^{max}, the binding constraint for lending agents, (LEND1), is below the binding constraint for borrowing agents, (BOR1).

$$\begin{aligned} & \text{(BOR1)} \geq \text{(LEND1)} \\ \Leftrightarrow \quad & (C + D^{max})\left(\frac{1}{2} - \psi\right) a^* \left(\frac{1}{2} + \psi\right) x - \left(\frac{1}{2} - \psi\right) a^* r D^{max} - \frac{1}{4}Cxa^* \geq \frac{1}{2}(1 + a^*)\left(\frac{1}{2} - \psi\right) rC - \frac{1}{4}Cxa^* \\ \Leftrightarrow \quad & (C + D^{max})a^* \left(\frac{1}{2} + \psi\right) x - a^* r D^{max} \geq \frac{1}{2}(1 + a^*) rC \\ \Leftrightarrow \quad & a^*(C + D^{max})x - a^* r D^{max} \geq rC + a^* rC \\ \Leftrightarrow \quad & a^*(C + D^{max})(x - r) \geq rC \\ \Leftrightarrow \quad & D^{max}(x - r) \geq rC \\ \Leftrightarrow \quad & r \leq \frac{xD^{max}}{C + D^{max}}. \end{aligned}$$

Note that we use both the lower bound of (BOR1) and the upper bound of (LEND1) with $a_i = a^*$.

Claim: Denote $\tilde{r} = \frac{xD^{max}}{C+D^{max}}$. The level of debt D^{max}, where the relevant participation constraints of borrowing and lending agents evaluated at the interest rate $\tilde{r}$ is zero, is larger than the interception of (BOR1) and (BOR2) (and (LEND1) and (LEND2), respectively).

$$
\begin{aligned}
& & \text{(LEND1)}(\tilde{r}) = 0 (= \text{(BOR1)}(\tilde{r})) \\
\Leftrightarrow & & \frac{1}{2}(1+a^*)\left(\frac{1}{2} - \psi\right)\tilde{r}C - \frac{1}{4}Cxa^* = 0 \\
\Leftrightarrow & & \frac{1}{2}(1+a^*)\frac{C + D^{max} - a^*D^{max}}{2(C+D^{max})}a^*xC - \frac{1}{4}Cxa^* = 0 \\
\Leftrightarrow & & \frac{a^*Cx(C - a^*D^{max})}{4(C+D^{max})} = 0 \\
\Leftrightarrow & & (D^{max})^2 - D^{max}C - C^2 = 0.
\end{aligned}
$$

Since D is assumed to be positive, we find the relevant participation constraints evaluated at the equilibrium interest rate to be zero at

$$D^{max} = \frac{1+\sqrt{5}}{2}C.$$

Thus, in order to be (BOR1) and (LEND1) the binding constraints,

$$
\begin{aligned}
D^{max} = & & \frac{1+\sqrt{5}}{2}C > \frac{4C}{x-4} \\
\Leftrightarrow & & x > 4 + \frac{8}{1+\sqrt{5}}.
\end{aligned}
$$

2.A.7 Proof of Proposition 2.7

Suppose $r^{eq} = \frac{D^{max}x}{(C+D^{max})}$. Note that $\frac{D}{C+D} < \frac{2C+D}{C+D}$. Hence, according to Appendix 2.A.2, the borrowing decision is $D_i = D^{max}$.

Consider some bank a' for which $E(\pi^{y_i}|a_i = a', y_i = y^*) > E(\pi^D|a_i = a')$. Since $\frac{\partial E(\pi_i^{y_i})}{\partial a_i} > 0$ and $\frac{\partial E(\pi_i^D)}{\partial a_i} = 0$, $\forall a'' > a'$ we have $E(\pi^{y_i}|a_i = a'', y_i = y^*) > E(\pi^D|a_i = a'')$. Similar to this, $\forall a'''' < a'''$ with $E(\pi^{y_i}|a_i = a''', y_i = y^*) < E(\pi^D|a_i = a''')$ we have $E(\pi^{y_i}|a_i = a'''', y_i = y^*) < E(\pi^D|a_i = a'''')$.

For bank $a^* = \frac{D^{max}}{C+D^{max}}$, the interest rate r^{eq} solves $E(\pi^{y_i}|a_i = a^*, y_i = y^*) = E(\pi^D)|a_i = a^*)$:

$$
\begin{aligned}
& (C+D^{max})a^*(1-y^*)xy^* - r^{eq}a^*(1-y^*)D^{max} - C = \frac{1}{2}(1+a^*)(1-y^*)Cr^{eq} - C \\
\Leftrightarrow\ & D^{max}\left(\frac{1}{2} + \frac{D^{max}r^{eq}}{2(C+D^{max})x}\right)x - \frac{r^{eq}(D^{max})^2}{(C+D^{max})} = \frac{1}{2}\frac{C+2D^{max}}{(C+D^{max})}r^{eq}C \\
\Leftrightarrow\ & \frac{1}{2}D^{max}x + \frac{(D^{max})^2}{2(C+D^{max})x}x\frac{D^{max}x}{(C+D^{max})} - \frac{(D^{max})^2}{(C+D^{max})}\frac{D^{max}x}{(C+D^{max})} = \frac{1}{2}\frac{C+2D^{max}}{(C+D^{max})}C\frac{D^{max}x}{(C+D^{max})} \\
\Leftrightarrow\ & \frac{1}{2}D^{max}x + \frac{1}{2}\frac{(D^{max})^3x}{(C+D^{max})^2} - \frac{(D^{max})^3x}{(C+D^{max})^2} = \frac{1}{2}\frac{(C+2D^{max})CD^{max}x}{(C+D^{max})^2} \\
\Leftrightarrow\ & D^{max}x(C+D^{max})^2 - (D^{max})^3x = C^2D^{max}x + 2C(D^{max})^2x.
\end{aligned}
$$

According to the argumentation above, demand in the deposit market is then given by $\int_{a^*}^{1} D^{max} di = (1-a^*)D^{max} = \left(\frac{C}{C+D^{max}}\right) D^{max}$ and supply by $\int_0^{a^*} C di = a^* C = \frac{D^{max}}{C+D^{max}} C$. Hence, the allocation solves the agents' problem and the deposit market clears.

2.A.8 Proof of Proposition 2.8

We have shown the existence of an intersection of r_1^{lend} and r_1^{bor} in the proof of Proposition 2.6 (Appendix 2.A.6). We now show that this intersection defines the equilibrium interest rate $r^{eq} = r_1^{bor}(D_i|D_i = D^{max}) = r_1^{lend}(a_i, D_i|a_i = a^*, D_i = D^{max})$:

$\forall r^{eq} \leq r_1^{bor}(D_i|D_i = D^{max}$, the demand in the deposit market is given by $\lim_{D^{max}\to\infty}(1 - a^*) \cdot D^{max}$ and 0 otherwise. The supply is given by $a^* C \; \forall r^{eq} \geq r_1^{lend}$ and 0 otherwise. Denote the individual lending volume at which $r_1^{bor}(D_i|D_i = D^{max})$ and $r_1^{lend}(a_i, D^{max}|a_i = a^*, D_i = D^{max})$ intersect by D_{uc}^{max}. Since $r_1^{lend}(a_i, D^{max}|a_i = a^*, D_i = D^{max}) > r_1^{bor}(D_i|D_i = D^{max}) \; \forall D^{max} > D_{uc}^{max}$, maximum supply in the deposit market is given by $a_{crit}^* = a^*(D_{uc}^{max})C$. Since demand for debt financing $\to \infty$ if $D^{max} \to \infty$ (due to $\frac{\partial((1-a^*)\cdot D^{max})}{\partial D^{max}} > 0$) and the equilibrium interest rate tries to balance demand and supply, $r^{eq} = r_1^{bor}(D_i|D_i = D_{uc}^{max}) = r_1^{lend}(a_i, D^{max}|a_i = a_{crit}^*, D_i = D_{uc}^{max})$.

Banks have no incentive to offer a higher interest rate $r_i > r^{eq} = r_1^{bor}(D_i|D_i = D_{uc}^{max})$ since for $r_i > r_1^{bor}(D_i|D_i = D_{uc}^{max})$, it is optimal to invest only $(C + D^{max})$ into the risky project. Since there is excess demand, accepting only a lower interest rate $r_i < r^{eq}$ by some bank $i \in I$ leads to $D_i = 0$. This is equivalent to investing $(C + D^{max})$ into the risky project, which is not optimal. Hence, banks have no incentive to deviate.

Suppose some lending agent $j \in I$. Accepting only some interest rate $r_j > r^{eq}$ leads to a demand of 0, because of $r_j > r_1^{bor}(D_i|D_i = D_{uc}^{max}) = r^{eq}$. By construction, investing $(C + D^{max})$ at a equilibrium interest rate r^{eq} is not optimal for agent j. Offering an interest rate $r_j < r_1^{bor}(D_i|D_i = D_{uc}^{max})$ can also not be optimal because profits from lending in the deposit market are increasing in r_j. Hence, lending agents have no incentive to deviate.

Obviously, the market equilibrium as the equilibrium in the deposit market does also hold for all finite $D^{max} > D_{uc}^{max}$.

2.B Equilibrium Interest Rate

Solve for equilibrium interest rate r^{eq}:

$$\begin{aligned}
& (C+D)\left(\frac{1}{2}-\psi\right)a^*\left(\frac{1}{2}+\psi\right)x-\left(\frac{1}{2}-\psi\right)a^*rD-C=\frac{1}{2}(1+a^*)\left(\frac{1}{2}-\psi\right)rC-C \\
\Leftrightarrow\quad & (C+D)a^*\left(\frac{1}{2}+\psi\right)x-a^*rD=\frac{1}{2}(1+a^*)rC \\
\Leftrightarrow\quad & (C+D)\frac{D}{C+D}\left(\frac{1}{2}+\frac{rD}{2(C+D)x}\right)x-\frac{D}{C+D}rD=\frac{1}{2}\left(1+\frac{D}{C+D}\right)rC \\
\Leftrightarrow\quad & D\frac{(C+D)x+rD}{2(C+D)x}x-\frac{rD^2}{C+D}=\frac{1}{2}\frac{C+2D}{C+D}rC \\
\Leftrightarrow\quad & Dx(C+D)+rD^2-2rD^2=(C+2D)rC \\
\Leftrightarrow\quad & r^{eq}=\frac{Dx}{(C+D)}.
\end{aligned}$$

$$\frac{\partial r^{eq}}{\partial D}=\frac{x(C+D)-Dx}{(C+D)^2}=\frac{xC}{(C+D)^2}.$$

$\Rightarrow$ for any D, we have $\frac{\partial r^{eq}}{\partial D}>0$.

2.C Moral Hazard and Allocation Effect

From the expected profit from deposit lending,

$$E(\pi^D)=\frac{1}{2}(1+a^*(D^{max}))(1-y(D^{max},r))rC,$$

we get the allocation effect:

$$AE=\frac{1}{2}a^*(D^{max})=\frac{D^{max}}{2(C+D^{max})}.$$

Since equity capital is exogenously given, the allocation effect depends only on D^{max} according to

$$\frac{\partial AE}{\partial D^{max}}=\frac{C}{2(C+D^{max})^2}>0.$$

As the comparative statics points out, an increase in the volume of additional funds from depositors D^{max} leads to a stronger allocation effect.

From optimal project choice

$$y^*=\frac{1}{2}+\frac{rD^{max}}{2(C+D^{max})x},$$

we get the moral hazard effect:

$$MHE=\frac{rD^{max}}{2(C+D^{max})x}.$$

The moral hazard effect depends not only on D^{max}, but also on the interest rate that has to be paid for deposits. The equilibrium interest rate, however, is also depending on D^{max} (see Appendix 2.B). Then the moral hazard effect depends on D^{max} according to

$$\frac{\partial MHE}{\partial D^{max}} = \frac{C\left[\frac{\partial r^{eq}}{\partial D^{max}} \cdot D^{max} + r^{eq}\right] + \frac{\partial r^{eq}}{\partial D^{max}} \cdot (D^{max})^2}{2(C + D^{max})^2 x} > 0.$$

Since the first derivative of r with respect to D^{max} is positive, we find an increasing moral hazard effect if the volume of additional funds from depositors D^{max} increases. Thus, the decrease of D^{max} (equivalent to a stricter regulation) on the one hand weakens the allocation effect, which is negative for the aggregate expected profits, but on the other hand also decreases the moral hazard effect.

2.D Various degrees of heterogeneity

2.D.1 Moral Hazard Effect

$$\begin{aligned} MHE &= \frac{D^{max}}{2(C + D^{max})x} r^{eq} \\ &= \frac{D^{max}(\overline{a}(D^{max} - C) + C)}{2(C + \overline{a}D^{max})(C + D^{max})} \end{aligned}$$

with

$$r^{eq} = \frac{\overline{a}(D^{max} - C) + C}{(C + \overline{a}D^{max})} x.$$

$$\begin{aligned} \frac{\partial MHE}{\partial D^{max}} &= \frac{C}{(C + D^{max})^2 x} r^{eq} + \frac{D^{max}}{2(C + D^{max})x} \frac{\partial r^{eq}}{\partial D^{max}} > 0. \\ \frac{\partial^2 MHE}{\partial D^{max} \partial \overline{a}} &= \frac{C}{(C + D^{max})^2 x} \frac{\partial r^{eq}}{\partial \overline{a}} + \frac{D^{max}}{2(C + D^{max})x} \frac{\partial^2 r^{eq}}{\partial D^{max} \partial \overline{a}} \\ &= \frac{C^2}{(C + D)^2 (C + \overline{a}D)^3} \left(\sqrt{\overline{a}} D^{max} + C\right) \left(\sqrt{\overline{a}} D^{max} - C\right). \end{aligned}$$

Thus,

$$\begin{aligned} \frac{\partial^2 MHE}{\partial D^{max} \partial \overline{a}} &< 0, \text{if} \sqrt{\overline{a}} < \frac{C}{D^{max}}, \\ \frac{\partial^2 MHE}{\partial D^{max} \partial \overline{a}} &= 0, \text{if} \sqrt{\overline{a}} = \frac{C}{D^{max}}, \\ \frac{\partial^2 MHE}{\partial D^{max} \partial \overline{a}} &> 0, \text{if} \sqrt{\overline{a}} > \frac{C}{D^{max}}. \end{aligned}$$

2.D.2 Optimal Capital Regulation

$$\begin{aligned} AP &= \frac{1}{\overline{a} - \underline{a}} \int_{a^*}^{\overline{a}} [(C + D^{max})(1-y)a_i yx]\, da_i - C \\ &= \frac{\overline{a} - a^*}{\overline{a} - \underline{a}} \left[(C + D^{max}) \frac{1}{2} (\overline{a} + a^*)(1-y)yx \right] - C. \end{aligned}$$

Using $y = \frac{1}{2} - \frac{r^{eq} D^{max}}{2(C+D^{max})x}$, $a^* = \frac{\overline{a}(D^{max}-C)+C}{C+D^{max}}$ and $r^{eq} = \frac{\overline{a}(D^{max}-C)+C}{C+\overline{a}D^{max}} x$, and defining $\widetilde{MHE}$ as the moral hazard effect without the interest rate (i.e., the pure 'skin in the game effect') and AA as the average ability of banks, we find

$$\begin{aligned} AP &= Cx \left[\left(\frac{1}{4} - \underbrace{\frac{(D^{max})^2}{4(D^{max}+C)^2 x^2}}_{\widetilde{MHE}^2} \underbrace{\frac{x^2(\overline{a}(D^{max}-C)+C)^2}{(\overline{a}D^{max}+C)^2}}_{(r^{eq})^2} \right) \underbrace{\frac{1}{2} \left(\frac{2\overline{a}D^{max}+C}{(D^{max}+C)} \right)}_{AA} \right] - C \\ &= \frac{1}{4} Cx \cdot AA - Cx \cdot AA \cdot \widetilde{MHE}^2 \cdot (r^{eq})^2 - C. \end{aligned}$$

Denote $D^{max} = D$. Taking the first derivative wrt D:

$$\begin{aligned} \frac{\partial AP}{\partial D} &= Cx \left[\frac{1}{4} \frac{\partial AA}{\partial D} - \frac{\partial AA}{\partial D} \widetilde{MHE}^2 \cdot (r^{eq})^2 - AA \cdot \frac{\widetilde{MHE}^2}{D} \cdot (r^{eq})^2 - AA \cdot \widetilde{MHE}^2 \cdot \frac{(r^{eq})^2}{D} \right] \\ &= Cx \left[\frac{C(2\overline{a}-1)}{8(C+D)^2} - \frac{C(2\overline{a}-1)D^2 x^2 (\overline{a}(D-C)+C)^2}{8x^2(C+D)^4(\overline{a}D+C)^2} - \frac{(2\overline{a}D+C)CDx^2(\overline{a}(D-C)+C)^2}{4x^2(C+D)^4(\overline{a}D+C)^2} \right. \\ &\quad \left. - \frac{(2\overline{a}D+C)D^2 2\overline{a}^2 C x^2 (\overline{a}(D-C)+C)}{8x^2(C+D)^3(\overline{a}D+C)^3} \right]. \end{aligned}$$

The characteristic equation is then given by:

$$\begin{aligned} (\overline{a}D+C)^3(C+D)^2(2\overline{a}-1) = &(\overline{a}(D-C)+C)^2(\overline{a}D+C)D^2(2\overline{a}-1) \\ &+ (\overline{a}(D-C)+C)^2(\overline{a}D+C)2D(2\overline{a}D+C) \\ &+ (\overline{a}(D-C)+C)2D^2\overline{a}^2(2\overline{a}D+C)(C+D). \end{aligned}$$

Chapter **3**

Excessive Credit and Bank Risk

3.1 Introduction

The Basel Committee on Banking Supervision (BCBS) in 2010 published for consultation the countercyclical capital buffer proposal with the aim to "achieve the broader macro-prudential goal of protecting the banking sector from periods of excess aggregate credit growth that have often been associated with the build up of system-wide risk."(Basel Committee on Banking Supervision (2010a), p.1) As the BCBS has suggested, national authorities should set the countercyclical capital buffer rate quarterly for exposures located in their country on the basis of the credit-to-GDP gap that has been found to be the best single indicator for the buildup phase of financial crises within a three-year horizon (see, for example, Drehmann, Borio, and Tsatsaronis (2011)). This approach, however, would only be appropriate if a large credit gap translates in an increase in the contribution to systemic risk for all banks with an ongoing credit relation to the private sector of the credit booming country. In contrast, it would be ineffective if a large credit gap comes to a shift in bank risk preferences and financial institutions domiciled in credit booming countries choose endogenously higher asset risk.

This chapter of the thesis sheds light on this issue and analyzes the causes of why the credit-to-GDP gap has been found to be a good predictor of banking crises. We investigate two types of bank risk that might increase the probability of a financial crisis in times of excessive credit. On the one hand, financial distress could become more likely due to increasing systemic risk, which can arise from the economic context or from a change in behavior of competitor banks (exogenous increase in banks' systemic risk contribution). On the other hand, vulnerabilities could arise if all banks domiciled in a credit booming economy would change their asset structure and choose a strategy with higher idiosyncratic asset risk.[1] It is important to differentiate between an exogenous increase in bank systemic risk and an endogenous change in bank behavior because of the different implications for regulation.

The chapter thus goes one step ahead of the literature predicting financial distress on the macro level by investigating the contribution of systemic risk and asset risk on the bank level. Regarding the macro view, there is the key lesson of past financial crashes that credit, besides being a necessary prerequisite for economic growth, sets seeds for financial crises (see, for example, Kindleberger (1978), Minsky (1986), and Reinhart and Rogoff (2009)). It has been argued that this outcome results from the mutually reinforcing processes of the financial sector and the real economy and the associated buildup of systemic risk. Hence, the main goal of the regulatory framework for countercyclical capital buffers has been to strengthen the defense of banks against systemic risk. However, this regulation would not enhance the resilience of the banking system if the increase in the likelihood for financial distress does solely arise from a change in banks' asset risk and banks' risk attitudes.

This chapter also goes ahead of the pure micro literature, which analyzes the deterioration of lending standards at a bank during a lending boom. As this literature on the micro level regarding the relation between a lending boom of a bank and its lending standards suggests, a bank-specific increase in the lending volume goes along with a deterioration of lending standards. We investigate whether financial institutions do not only choose riskier assets during a lending boom, but whether they behave similarly once they observe an economy-wide credit boom. There are two theoretical arguments regarding why banks that are not promoting the credit boom could be affected by an economy-wide credit expansion. The first mechanism follows the argument of distorted incentives in Rajan (1994). In this paper, bank managers fear the pressure of shareholders and make bad credit decisions especially when competitors increase the provision of loans. While this "keeping up with the Goldman's" behavior is also discussed in Aikman, Haldane, and Nelson (2015), these authors provide a second mechanism for why the asset risk of institutions domiciled in credit booming economies could be affected by excessive credit. There are only a limited number of good projects available within an economy, and if good projects have already been financed by a competitor, a bank's marginal credit will be more risky, even if the bank itself has not experienced a lending boom.

This chapter combines the macro view with the micro literature and analyzes whether an excessive credit boom leads to an increase in a bank's contribution to systemic risk

[1] Note that an active adjustment of the asset structure would also shift banks' contribution to systemic risk.

due to macro-economic factors or whether it incentivizes banks to engage in riskier activities, which would result in an increase in banks' asset risk. Note that we investigate the asset risk of an institution for a given loan growth and thus go beyond the literature of banks' lending growth and lending standards. The chapter thus sheds light on the impact of excessive credit on the behavior of banks domiciled in that country, even if these institutions were not the driving forces of the credit boom. Consequently, we investigate with an exogenous increase in systemic risk and an endogenous increase in asset risk — two very different potential channels — why excessive credit has been found to be a good predictor for financial crises.

We find evidence for both an exogenous increase in systemic risk that remains effective ceteris paribus banks' asset risk and is partly driven by the economic context, and an endogenous increase in banks' asset risk in times of an excessive credit boom. Regarding the exogenous increase in systemic risk, we find that the economic perspective as well as asset prices in the real estate sector do affect banks' contribution to systemic risk via the economic context channel. The positive correlation between excessive credit and bank systemic risk remains in place if we control for these factors in almost all specifications. Moreover, we observe a strong correlation between excessive credit and banks' asset risk, which does not vanish once we control for the economic context. Note that we include a number of bank characteristics in all of our specifications that might affect both the credit provision to the private sector and banks' assets and its contribution to systemic risk in order to rule out that the observed correlation between excessive credit and the two types of bank risk is not driven by third factors. These findings suggest that the large predictive power of financial crises by the credit-to-GDP gap is partly driven by exogenous factors such as the economic context, and partly driven by a shift in bank behavior. Thus, countercyclical capital buffers can be effective in preventing financial distress that arises from an exogenous increase in systemic risk. The measure, however, does not adequately address the incentives to engage in high risk assets, which might arise in times of excessive credit from an accentuation of competition.

The remainder of this chapter is organized as follows. Section 3.2 introduces the literature that is related to the chapter. Section 3.3 provides a description of the data, especially the credit-to-GDP gap as well as the measures of banks' contribution to systemic risk and banks' asset risk, and includes descriptive statistics. Section 3.4 presents the empirical analysis of the hypotheses and a description of the empirical model. The results are shown in Section 3.5 followed by a brief conclusion in Section 3.6.

3.2 Related Literature

Since the aim of this chapter of the thesis is the analysis of bank risk in times of an economy-wide credit boom, the chapter relates to the work on extensive credit expansion.

On the macro level, the role of excessive credit has been identified as a key leading indicator to predict a financial crisis. Schularick and Taylor (2012), for example, collect historical credit data in order to investigate the relation between credit and the likelihood of a financial crisis. They observe in their long-run data sample that a higher credit-to-GDP level leads to an increase in the probability of a financial crisis occurrence. The paper by Aikman, Haldane, and Nelson (2015) confirms this finding of a positive correlation between the pickup in the credit-to-GDP ratio and the occurrence of a banking crises within the past 100 years. For a sample of 14 countries, the paper finds a strongly significant relationship between the growth in the ratio of credit-to-GDP and the probability of banking distress. While these two papers use the growth in the credit-to-GDP ratio as a measure of excessive credit, there are several papers that provide evidence for the same result using the difference between the credit-to-GDP ratio and its long-term trend (credit-to-GDP gap) as an indicator of excessive credit. In fact, the literature found the credit-to-GDP gap to be the best single leading indicator for the buildup phase to financial crises within a three-year horizon (Drehmann, Borio, and Tsatsaronis (2011)) or for systemic banking crises using an evaluation period that lasts from five years to one year prior to a crisis (Detken, Weeken, Lucia, Bonfim, Boucinha, Castro, Frontczak, Giordana, Giese, Jahn, Kakes, Klaus, Lang, Puzanova, and Welz (2014)). This conclusion has not only been based on the average performance of the credit-to-GDP gap as a measure of excessive credit for a group of countries,[2] but also on the performance of the credit-to-GDP gap as a measure of excessive credit in individual countries (see, for example, Giese, Andersen, Bush, Castro, Farag, and Kapadia (2014), Gerdrup, Kvinlog, and Schaaning (2013), or Deutsche Bundesbank (2012)).

The micro level provides one potential explanation for this observation. Here, a bank-specific lending boom has been found to lead to a deterioration of this bank's lending standards. Dell'Ariccia and Marquez (2006) show a theoretical approach that reflects this relationship. They describe the interaction between the informational structure of loan markets and banks' strategic behavior in determining the volume of lending, the lending standards, and the aggregate allocation of credit. In their framework, low bank profitability, high aggregate credit, and high vulnerabilities to macroeconomic shocks result from an increase in the proportion of unknown projects in the economy. A second theoretical

[2] See additionally, for example, Alessi and Detken (2011), Behn, Detken, Peltonen, and Schudel (2013), Drehmann and Tsatsaronis (2014), or Drehmann and Juselius (2014).

argument for the deterioration of lending standards is given by Ruckes (2004) who attributes the changes in bank lending standards to changes on the lenders' demand side. In his model, banks compete on price for extending loans to borrowers, and it is rational for banks to rely not only on their own assessment, but also to take the quality of competing banks' information into account. Thus, banks do not evaluate applicants thoroughly in different phases of the business cycle, which prompts the loosening of credit standards in times of a credit boom and the tightening of standards in a recession.

In addition to the theoretical literature, there are some empirical studies showing the relationship between rapid loan expansion and lower credit standards on the bank level. Jiménez and Saurina (2006), for example, analyze the impact of bank-level loan growth on banks' credit risk as well as on the loan-specific probability of default. On the bank level, they find a positive relationship between the non-performing loan ratio and the rate of loan growth within that bank with a lag of four years. On the individual loan level, Jiménez and Saurina (2006) obtain a higher likelihood to default in the following three and four years after an increase in the loan growth of a bank. Dell'Ariccia, Igan, and Laeven (2012) use loan-level application data to investigate the relation between credit expansion and loan denial rates in the most recent U.S. subprime mortgage boom with a strong focus on demand-side effects. In line with the findings on relaxed lending standards in credit booms, they obtain lower loan denials in areas that experienced faster credit growth. Additionally, they could observe that lenders put less weight on the applicant's repayment capacity measured by the loan-to-income ratio in areas with a fast credit expansion. The paper by Foos, Norden, and Weber (2010) analyzes the effect of bank-specific abnormal loan growth, defined as the difference in the loan growth rate between bank i and a country's aggregate loan amount, on loan losses, profitability, and the leverage ratio of the institutions. Using balance sheet data from 16,000 individual banks from 16 major countries, the paper finds a positive and highly significant influence of abnormal loan growth on subsequent loan losses with a lag of two to four years. Moreover, Foos, Norden, and Weber (2010) observe that a high abnormal loan growth is related to a lower interest income as well as lower capital ratios and, therefore, to a higher riskiness of individual banks.

Finally, this chapter relates to the literature that describes how potential channels for an economy-wide excessive credit boom might lead to higher asset risk at banks domiciled in the credit-booming country. For example, the paper by Rajan (1994) investigates the presence of herding behavior in aggregate credit booms. He shows that herding behavior can explain the provision of credit for negative net-present value projects when bank managers have not only a long-term horizon in making loan decisions, but also care about short-term concerns as, for example, their reputation. Besides maximizing the bank's earnings, the manager wants the stock market's or labor market's participants to have a good perception of his abilities. In his model, stock and labor market participants observe the bank's earning as the only signal and compare the performance of a bank manager with the performance of competitors. Therefore, a manager has strong incentives to boost current earnings at the expense of future earnings and to behave in a similar manner as his peers. Thus, this model would predict that in times of credit booms, banks do not only increase their asset risk due to poor loan decisions, but also their systemic risk due to herding behavior.[3] A second theoretical argument of why excessive credit might affect all banks within the economy is given by Aikman, Haldane, and Nelson (2015). Their model indicates that a limited supply of good-risk projects leads to riskier marginal-risk projects. Since banks benefit from a limited liabilities shield, their marginal return on choosing a risky rather than a safe portfolio causes an increase in the number of competitor banks that also choose the risky portfolio.[4]

3.3 Data

We analyze the relationship between excessive aggregate credit to the nonfinancial private sector and bank risk for institutions from the US, Japan, and 16 European countries during the period 2004 Q1 - 2013 Q4.[5] For all of these countries, we collect quarterly data on a broad measure of credit to the domestic non-financial private sector from the Bank for International Settlements (BIS) for the period 1960 Q1 to 2014 Q2.[6] According to Dembiermont, Drehmann, and Muksakunratana (2013), this time series captures not only credit that was provided by domestic banks, but accounts for borrowing from nonfinancial corporations, households and nonprofit institutions serving households from all sources independent of both the country of origin and the type of lender.[7] We further

[3]Rajan (1994) also provides some empirical support for his model. However, Gorton and He (2008) find no evidence for Rajan's reputation hypothesis.

[4]Aikman, Haldane, and Nelson (2015) also provide a second theoretical channel of why excessive credit leads to a higher crisis probability that is in line with the argumentation in Rajan (1994), i.e. a banker who cares about his career concerns ("Keeping up with the Goldmans").

[5]The set of European countries includes Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and the United Kingdom.

[6]Note that this long time series is used to derive a more precise filter, see the description of the credit-to-GDP gap in Subsection 3.3.1.

[7]The rationale to use this broad concept of credit, which recognizes that a bank can suffer the consequences of a period of excess credit growth even if it is not active in the lending business or not the driving forces behind the credit growth, is twofold. First, the measure recognizes banks' incentives for regulatory arbitrage for example by capturing the growth of credit from the shadow banking sector.

collect quarterly data of the countries' nominal GDP from the Organization for Economic Cooperation and Development (OECD) in order to observe the ratio of credit to GDP for the period from 1960 Q1 to 2014 Q2. Moreover, we collect on the country level data on house prices from the BIS. Since the BIS does not provide this data for all countries in our sample, we collect missing information from the European Central Bank (ECB). Since both series are indexes on residential property prices with different base years, we normalize the house price index to 100 units in the year 2000, the earliest date where the index is available for all countries in our sample.

In a next step, we gather information on the bank level. To this extent, we use Bureau van Dijk's Bankscope database and obtain annual balance sheet information of all listed banks from our country sample that have a total asset size of above US $ 25 billion.[8] We focus on listed banks in order to observe our measure of systemic risk, $\Delta CoVaR$, and our measure of asset risk, VaR, which are both based on the market value of total assets. As all data but the balance sheet information is available on a quarterly frequency, we use a linear interpolation to elevate the frequency of these bank characteristics from annually to quarterly. Moreover, we collect from Thomson Reuters Datastream information on banks' market value of equity, on various interest rates, and the CBOE Volatility Index from the Chicago Board Options Exchange in order to calculate our measure of bank asset risk, the value at risk, as well as our measure of bank systemic risk, the conditional value at risk. For both series, we first calculate the values on a daily frequency before we average daily observation over one quarter. Moreover, in order to deal with outliers in the daily observations, we winsorize the day-to-day risk variables on the 5/95 % level before calculating quarterly averages.

3.3.1 Measuring aggregate credit booms with the credit-to-GDP gap

The main variable of interest in our study is the standardized credit-to-GDP gap. We follow the Basel Committee on Banking Supervision (2010b), as well as the Recommendation of the European Systemic Risk Board (2014b) on guidance for setting countercyclical buffer rates and apply their methodology for the measurement and the calculation of

Second, a domestic firm or household that defaults on borrowing from a foreign institution or a domestic non-bank is also likely to default on its borrowing from domestic banks.

[8]We restrict our sample to large banks only in order to account for the fact that there are many small listed banks in the US and in Japan, while only large banks are listed in the stock market in most European countries. Moreover, we exclude the Swiss National Bank due to its special role as a central bank. See Appendix 3.B for an overview of all banks in the sample.

the credit-to-GDP gap.[9] The quarterly standardized credit-to-GDP gap for country j in period t is calculated as

$$GAP_{jt} = Ratio_{jt} - Trend_{jt} \tag{3.1}$$

where *Ratio* is defined as the quotient of a measure of the stock of credit to the private nonfinancial sector in country j and the gross domestic product.*Trend* measures the recursive Hodrick-Prescott filtered trend of the *Ratio* measure with a smoothing parameter lambda of 400,000 (see Hodrick and Prescott (1997)).

Figure 3.1 shows the credit-to-GDP ratio, -trend, and -gap for the US, the UK, and Germany. While we observe a strong increase in the credit-to-GDP ratio in the period from 1980 to 1990 and from 1998 to the start of the financial crisis for the US and for the UK, there is only a more moderate increase in the credit ratio in Germany in the years shortly before the onset of the financial crisis. Similarly, the credit-to-GDP gap of the US and the UK behave in a very similar manner while the picture looks slightly different for Germany. We find excessive credit provision in the US and in the UK between 1985 and 1992 and from 1998 until the outburst of the financial crisis in 2007. In Germany, however, we find only a short period of excessive credit around 1985 and from 1995 until 2005.

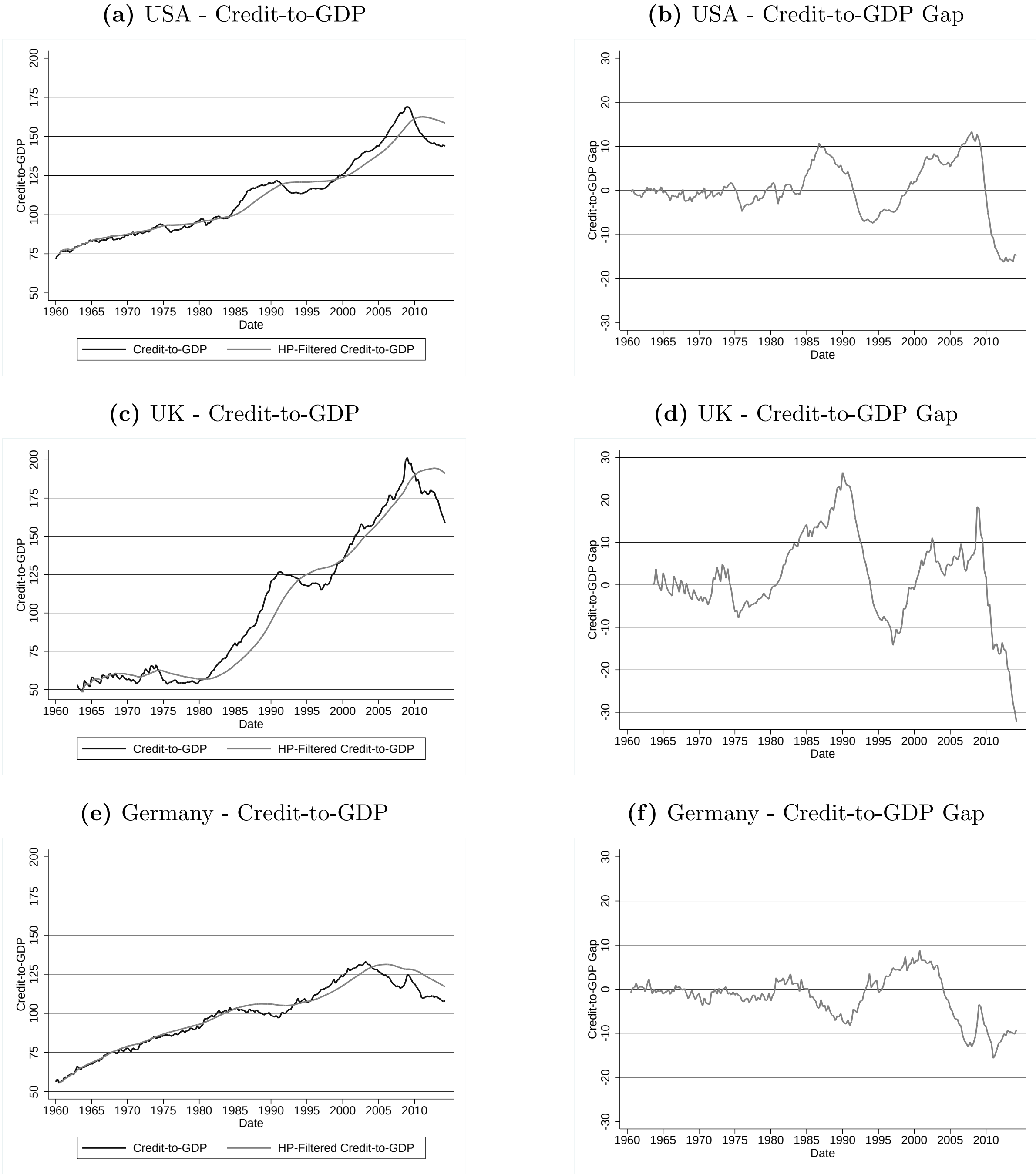
3.3.2 Measuring systemic risk within the financial sector by conditional value at risk

A bank's contribution to overall systemic risk should be higher the larger the repercussions of its failure on the financial system. In the theoretical literature, one distinguishes basically four different channels of contagion through which distress of one institution may spread to the rest of the financial system: (i) information contagion (Chen (1999) and Acharya and Yorulmazer (2008)), (ii) contagion via the interbank market (Allen and Gale (2000)), (iii) contagion via macro-economic feedbacks (Brunnermeier and Pedersen (2009)), and (iv) contagion from self-fulfilling expectations (Diamond and Dybvig (1983)). Following this theoretical literature, the magnitude of an institution's failure depends on its size, its correlation with other banks, its interconnectedness, as well as on the economic context.

We measure systemic importance within the financial system using the $\Delta CoVaR_t^i$ measure, which was introduced by Adrian and Brunnermeier (2011). This measure tries to

[9] The general guidance on the measurement and calculation of the deviation from long term trends of ratios of credit to gross domestic product has been assigned to the ESRB according to *Article 136* in the Capital Requirement Directive 2013/36/EU of the European Parliament and of the Council (CRD IV).

Figure 3.1: Credit-to-GDP series, - trend, and - gap



capture an individual institution's contribution to overall systemic risk within a financial system. Due to the comprehensive nature of this variable, it captures not only a bank's size, but also other factors, such as its correlation with other banks, as well as the economic context.

A bank's $CoVaR$ relative to the system is defined as the conditional value at risk, i. e.

the $q\% - VaR$ of the whole financial sector conditional on the fact that an institution i is at its VaR level:

$$CoVaR_q^{system|X^i=VaR_q^i} := VaR_q^{system}|VaR_q^i \tag{3.2}$$

It thus gives the maximum dollar loss of the financial system at probability q conditional on institution i being in distress. Throughout the chapter, we are using a stress level of 1%.

Following the procedure proposed by Adrian and Brunnermeier (2011), we estimate $CoVaR$ by using quantile regression, as is explained in more detail in Appendix 3.A. We allow for the time variation of $\Delta CoVaR_t^i$ by including a set of lagged state variables in the estimation. Our measure of systemic risk, $\Delta CoVaR_t^i$, is defined as the difference between $CoVaR_t^i$ conditioned on distress of bank i versus normal times, where normal times are characterized by the median. Hence, it is calculated as follows, using again the 1% stress level:

$$\Delta CoVaR_t^i(1\%) = CoVaR_t^i(1\%) - CoVaR_t^i(50\%). \tag{3.3}$$

From the quantile regressions, we obtain a panel of daily $\Delta CoVaR_t^i$, measuring the risk contribution of each individual institution to the financial system, where the system is defined as all banks in our sample. It should capture all the determinants of the financial contagion channels, i. e. the systemic importance deriving from correlation, size, interconnectedness, and from the economic context. Since $\Delta CoVaR_t^i$ is typically negative, with a more negative value indicating a larger contribution to systemic risk, we use $-\Delta CoVaR_t^i$ throughout the chapter, implying that an increase in this variable is to be interpreted as an increase in the contribution to systemic risk.

Figure 3.2 displays the time variation of the sample average $-\Delta CoVaR_t^i$ over the sample period. We see a sharp increase in the middle of 2007, and especially towards the end of 2008. Another spike shows up at the onset of the European debt crisis. A simple scatter plot for the relation between $-\Delta CoVaR$ and the credit-to-GDP gap, which we aim to explain in the empirical analysis, is shown in Figure 3.3.

3.3.3 Measuring bank asset risk by value at risk

We use the most common measure of risk used by financial institutions, the value at risk (VaR), which focuses on the risk of an individual institution in isolation. More precisely, we observe the value at risk at the 1% level for each bank's market value of total assets by regressing the return on market value of total assets on a set of lagged state variables, M_{t-1}, in a quantile regression and generating predicting values:

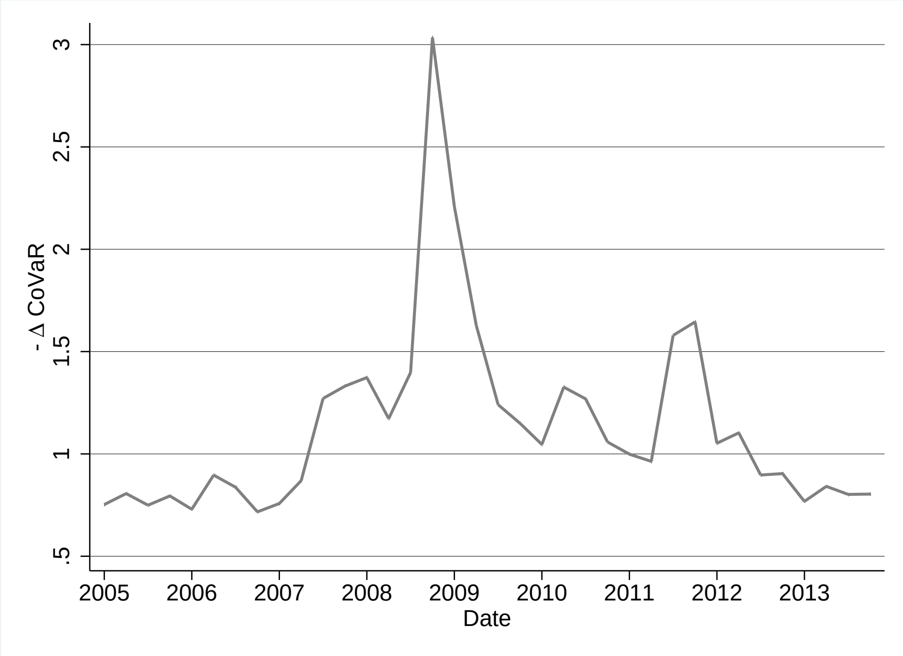


Figure 3.2: Evolution of $-\Delta CoVaR$ (sample average) over the sample period.

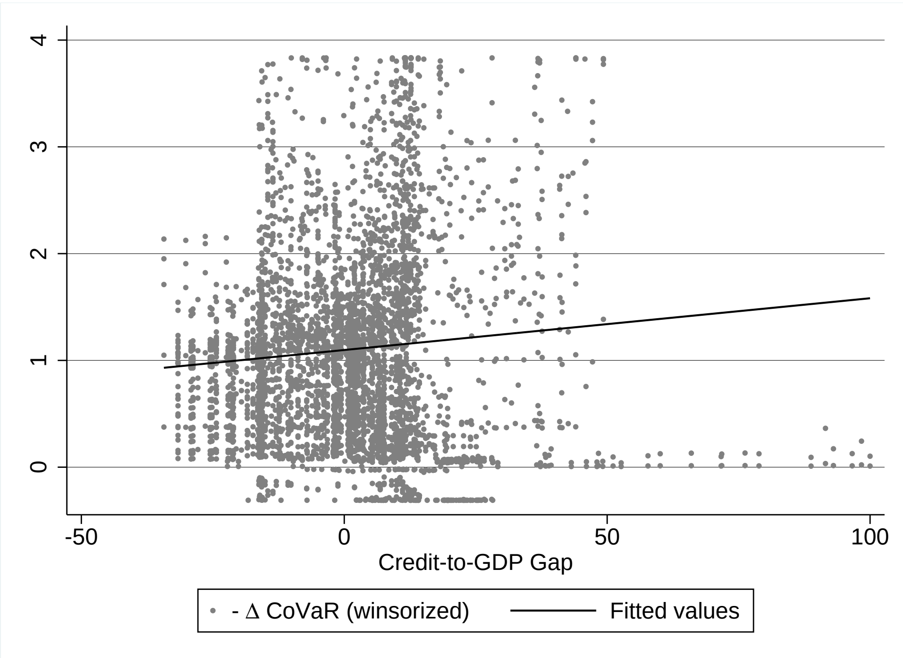


Figure 3.3: Scatter plot of $-\Delta CoVaR$ and the credit-to-GDP gap.

$$VaR_t^i(q) = \hat{\alpha}_q^i + \hat{\gamma}_q^i M_{t-1} \tag{3.4}$$

From these quantile regressions , we obtain a panel of daily VaR_t^i, measuring the maximum dollar loss within the 1% confidence interval that serves as a measure of a bank's idiosyncratic asset risk. Since a more negative number again indicates higher risk, we use $-VaR$ throughout the chapter in order to simplify the interpretation.

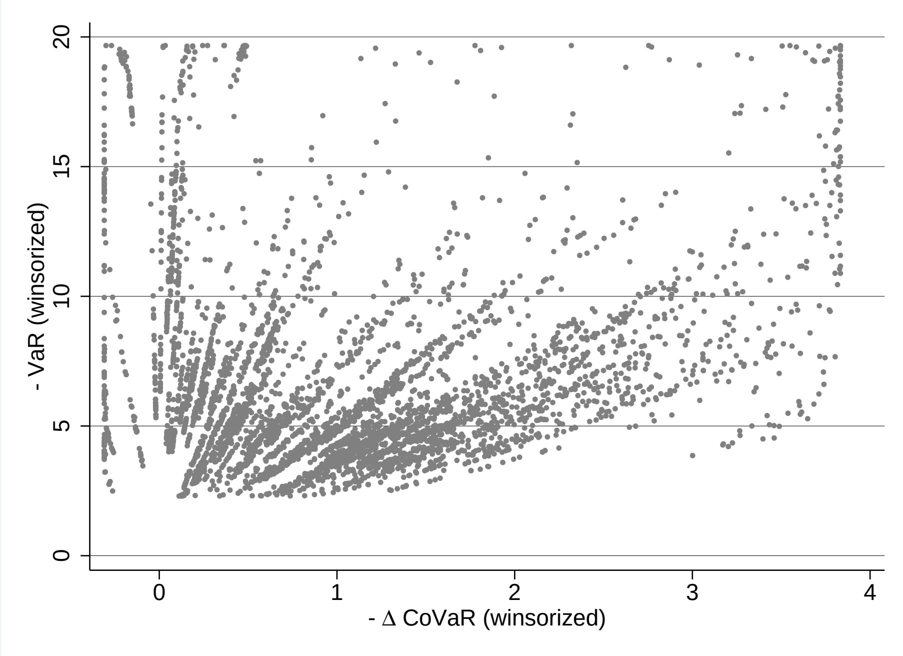


Figure 3.4: Scatter Plot of $-VaR$ and $-\Delta CoVaR$ (both series are winsorized).

The mean value of the VaR develops in a similar shape over time as the mean value of our systemic risk measure, $\Delta CoVaR$, since both variables signal a high risk in times of crises, just as they should. However, we find hardly a relationship between the two variables, as the scatter plot in Figure 3.4 demonstrates. Banks with a high asset risk do not necessarily have a high systemic relevance, which is reflected by a low correlation between the two variables of only 0.1540. For example, we find a high VaR for Freddie Mac, Fannie Mae, Allied Irish Banks, Huntington Bancshares, Dexia, or Regions Financial Corporation in 2008 Q4, while the highest systemic risk measure $\Delta CoVaR$ is found for BNP Paribas, UBS, ING Groep, Goldman Sachs, and Morgan Stanley in 2008 Q4.

The relation between $-VaR$ and the credit-to-GDP gap, which we aim to explain in the empirical analysis, is shown in the scatter plot in Figure 3.5.

3.3.4 Descriptive statistics

We present descriptive statistics of bank and country characteristics in Table 3.1. The average value at risk of all banks in our sample is 6.78, the maximum value being 59.77, realized at Freddie Mac in the fourth quarter in 2008. Furthermore, the sample average of our systemic risk measure, $-\Delta CoVaR$, yields 1.14, which is very much of the same magnitude as in Adrian and Brunnermeier (2011). Banks in our sample show an average loan growth per quarter of 1.6 %. The highest loan growth was observed for the mortgage

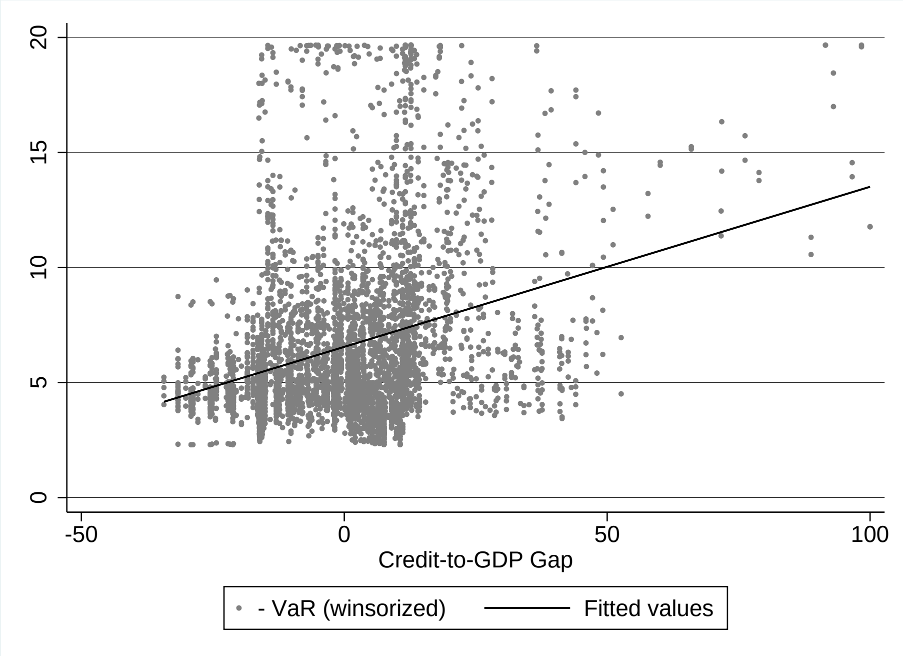


Figure 3.5: Scatter plot of $-VaR$ and the credit-to-GDP gap.

banks Freddie Mac and Fannie Mae in the year 2010. The largest bank in terms of total assets is found to be the Royal Bank of Scotland with a total asset size of US$ 3,731 billion in 2007. The average return on assets is 0.43, with the National Bank of Greece being the institution with the highest loss in terms of asset return. The average leverage indicates that the sample mean ratio of total assets to equity is 42.37 with an immense leverage of more than 2,400 found at Fannie Mae due to a very low equity.[10] Note that we replace observations of negative leverage arising from negative equity with the largest value of leverage that has been observed in our sample. On the country level, we obtain an average ratio of total credit to GDP of 166.69 with the lowest ratio of 76.69 in Greece in 2005 Q1 and the largest credit ratio of 336.09 found in Ireland in 2012 Q2. The largest deviation of total credit from the trend is also found in Ireland in the fourth quarter of 2009. Moreover, we find an average quarterly GDP growth rate of 0.4% within our sample, with the largest drop in GDP of 8.5% in Norway in the first Quarter 2009, and the fastest growth rate of 7.0% observed in Ireland in 2007 Q1. Finally, the house price index, which has been normalized to 100 for the year 2000, shows a mean value of 133.35, with the highest value found in Austria in the years after the financial crisis as well as in Spain in 2007, and the lowest values are shown in Japan in 2013.

[10] In fact, this huge leverage is due to the linear interpolation from a positive to a negative value of equity.

Table 3.1: Summary statistics

Variable	Mean	Std. Dev.	Min.	Max.	N
$-VaR$	6.781	4.425	1.62	59.766	4284
$-VaR$ (winsorized)	6.611	3.644	2.301	19.669	4284
$-\Delta CoVaR$	1.14	1.124	-3.015	17.035	4284
$-\Delta CoVaR$ (winsorized)	1.101	0.899	-0.31	3.833	4284
Loan Growth	0.016	0.081	-0.971	3.357	4166
log(Total Assets)	19.1	1.289	17.069	22.06	4283
ROA	0.433	1.022	-10.83	9.779	4281
Leverage	42.365	230.814	1.807	2425.144	4283
(total) credit-to-GDP	166.69	33.9	76.687	336.085	4284
(total) credit-to-GDP gap	0.824	15.804	-34.299	99.995	4284
GDP Growth	0.004	0.012	-0.085	0.07	4284
Housepriceindex	133.351	49.661	61.33	252.4	4284

3.4 Empirical Analysis

3.4.1 Hypotheses

Our empirical analysis aims to explain bank systemic risk and bank asset risk, two types of risk that could yield to a full-blown financial crisis. In this respect, we analyze whether the regulatory measure of countercyclical capital buffer can be effective in preventing financial distress given the regulatory framework based on the credit-to-GDP gap.

We postulate three hypotheses that will be tested in the empirical analysis. The first hypothesis refers to the increase in the crisis probability due to an exogenous amplification of banks' contribution to systemic risk in times of excessive credit. Keep in mind that our measure of systemic risk, $\Delta CoVaR$, should capture an institution's contribution to systemic risk emanating from its size, its asset correlation with other banks as well as from the economic context. Therefore, the systemic risk contribution of a financial institution could increase exogenously without the bank having changed its asset or liability portfolio due to externalities arising from competitor banks and from the economic context. In the literature, where the credit-to-GDP gap has been found to be a good indicator for financial distress, it has often been literally argued that a large credit-to-GDP gap provides a reliable signal for the buildup of systemic risk (see, for example, Drehmann, Borio, and Tsatsaronis (2011)). In line with this literature, we expect that the systemic risk contribution of financial institutions domiciled in credit booming economies to be higher, as postulated in Hypothesis 3.1.

Hypothesis 3.1 ('Bank Systemic Risk')**.** *Ceteris paribus, bank systemic risk is higher for banks domiciled in countries with an excessive credit boom.*

As the first hypothesis refers to correlation rather than causality, we want to rule out a spurious relationship between credit and systemic risk. This exercise helps us to understand whether the (expected) positive correlation between excessive credit and systemic risk is only driven by third factors. We explore the general economic conditions and prospects as the first potential candidate that might yield to higher credit and could simultaneously affect banks' systemic risk contribution, and the rapid growth of asset prices as a second one. As the economy grows, the income of financial institutions increases, which gives more room for additional credit provision that could result in a more procyclical financial system and thus, to an increase in the systemic risk contribution of institutions due to the economic context. Similarly, a boom in the real estate sector that weakens the external funding constraints of banks can easily result in herding behavior by financial institutions and might lead to higher credit demand by the private sector. Therefore, if both credit and systemic risk were increasing due to a boom of the real economy or due to a rapid increase in property prices, we would expect that both the growth rate of GDP and the property price index to have a positive effect on systemic risk, while we expect no significant effect on the credit gap. This leads us to Hypothesis 2a.

Hypothesis 2a ('Economic Context and Systemic Risk')**.** *Ceteris paribus, bank systemic risk is higher for banks domiciled in a booming economy and in countries with high property prices.*

We further examine nonlinear effects of excessive credit and investigate whether the effect of the credit-to-GDP gap on systemic risk depends on the economic context. For example, the effect of a large credit gap might be particularly strong if the economy is in a recession, while a large, indebted private sector might be less severe as long as property prices are high. One would expect that the buildup of systemic risk from excessive credit is the weaker the faster the economy growths and that it is weaker as long as property prices are high. This yields the prediction of Hypothesis 2b.

Hypothesis 2b ('Credit Gap and Economic Context')**.** *Ceteris paribus, the effect of excessive credit on bank systemic risk is higher for banks in countries with a declining GDP and the effect is smaller as long as house prices are high.*

In a third step, we investigate whether institutions respond to a macroeconomic credit boom with an increase in asset risk and thus whether the good performance of the credit-to-GDP gap in predicting financial distress is due to a shift in the quality of banks' asset portfolio. More precisely, we want to analyze if and how past excessive credit provision to the private sector in an economy by any finance provider affects the incentives of banks domiciled in this country to adjust their asset risk. Following the argument in Rajan (1994), banks that expect high profits of their competitors during the credit expansion phase fear being punished by the market if they underperform relative to their peers. That fear might provide an incentive for the bank to adjust the risk-return structure on its assets and to seek high risk investment opportunities. We thus expect that bank asset risk is higher in countries with an excessive credit provision ceteris paribus bank characteristics, especially for a given loan growth of individual banks. This leads us to Hypothesis 3.

Hypothesis 3 ('Bank Asset Risk')**.** *Ceteris paribus, bank asset risk is higher for banks domiciled in countries with an excessive credit boom.*

Note that this hypothesis goes beyond the finding that foregone abnormal loan growth by one institution leads to higher loan losses at that particular bank in the present. In fact, it examines more carefully whether excessive credit growth is found to be a good predictor of a financial crisis due to a change in bank asset risk rather than due to increasing systemic risk.

Summing up, our main hypotheses are that excessive credit is positively correlated with banks' contribution to systemic risk and banks' asset risk, and that the effect of the credit-to-GDP gap decreases in economic perspectives and in the level of asset prices. Since we analyze potential channels through which excessive credit could lead to an increase in banks' systemic risk, the investigation of these hypotheses helps us to understand the potential mechanisms that could cause an excessive credit boom to result in a higher probability of financial distress.

3.4.2 Empirical model

In our empirical analysis, we model banks' contribution to systemic risk and banks' asset risk as a function of a country-specific measure for excessive credit provided to the private sector, as it has been defined by the Basel Committee on Banking Supervision (2010b) (Basel gap). More precisely, we model the conditional value at risk as a measure of systemic risk and the value at risk as a measure of asset risk of bank i in country j at time t as follows:

$$\begin{aligned} BankRisk_{i,j,t} = \alpha + \sum_{k=1}^{4} \zeta_k \cdot BankRisk_{i,j,t-k} + \beta \cdot BaselGap_{j,t-1} \\ + \gamma \cdot W_{j,t-1} + \delta \cdot X_{i,j,t-1} + \mu_i + \rho_t + u_{i,j,t}. \end{aligned} \tag{3.5}$$

We include lags of the dependent variables up to one year (four quarters) in order to account for the persistence of the two types of bank risk. The variable of interest, *BaselGap*, depicts our measure for an excessive credit boom on the macroeconomic level. It is calculated as the current ratio of credit provided to the private nonfinancial sector to nominal GDP relative to its long-term trend, as it has been suggested by the Basel Committee for Banking Supervision and as it is used in the European framework of the Basel regulation. Since the literature has found that the credit-to-GDP gap is the best single indicator for predicting financial crises within a three-year horizon, we are interested in the effect of excessive credit on bank risk within this timespan. In the main analysis, we model the effect of excessive credit between year t and $t-2$ on bank risk. For this purpose, we calculate the moving average of the credit gap over eight quarters. As a robustness test, we analyze a more short-term effect of excessive credit and use a moving average over one year, as well as a more long-term effect with the moving average of the credit gap over 12 quarters. According to Hypothesis 3.1 ('Bank Systemic Risk') and Hypothesis 3 ('Bank Asset Risk'), we would expect that a higher level of excessive private credit is associated with a higher level of systemic risk and asset risk, respectively. Thus, we expect β to have a positive sign.

$X_{i,j,t}$ includes further bank-specific variables determining bank risk in terms of systemic risk contribution and asset risk of financial institutions, as described in Section 3.3. Note that the loan growth at the individual bank level is included in $X_{i,j,t}$, such that our variable of interest, the credit-to-GDP gap, reflects the effect on banks' contribution to systemic risk and banks' asset risk for a given level of individual loan growth. All explanatory variables enter the model with a lag of one period in order to mitigate endogeneity problems and to account for publication lags.

When we investigate potential mechanisms for why the credit-to-GDP gap might have found the high predictive power of financial distress, we additionally include with $W_{j,t-1}$ the growth rate of GDP and an index on the level of property prices in the regression as well as an interaction term of these variables with the credit-to-GDP gap. According to Hypothesis 2a ('Economic Context and Systemic Risk'), we expect γ to be positive, and according to Hypothesis 2b ('Credit Gap and Economic Context'), the coefficient of the interaction term of $W_{j,t-1}$ and $BaselGap_{j,t-1}$ is expected to be negative.

We apply two different techniques to estimate our model: An ordinary least squares (OLS) estimator and a linear dynamic panel generalized methods of moments (GMM) estimator, as proposed by Arellano and Bover (1995) and Blundell and Bond (1998). The latter of the two methodologies allows us to deal with potential endogeneity issues by instrumenting all endogenous right-hand side variables of the regression with their own lags. Note that system GMM estimators are designed for dynamic panels with "small-T, large-N", while we have a rather large time dimension of 39 quarters. Thus, we will have a large number of instruments that might result in a small Hansen Statistic even if we restrict the number of lags used as instruments to the minimum. In order to take the unobserved heterogeneity of banks over time into account, we include bank-specific fixed effects μ_i, as well as time fixed effects ρ_t. Moreover, we account for the autocorrelation of countries and cluster standard errors at the country level.[11]

3.5 Estimation Results

3.5.1 Excessive Credit and Systemic Risk

We first present in Table 3.2 the results for the analysis of whether an economy-wide excessive credit provision is associated with an increase in the systemic risk contribution of banks domiciled in the credit booming country. We show in column one and column three the results from the OLS regression with bank and quarter fixed effects, while column two and column four document the results of an Arellano and Bover (1995)/Blundell and Bond (1998)-type linear dynamic panel estimation.

Our findings indicate a positive correlation between the average credit gap within an economy over the past two years and the systemic risk contribution of banks resident in this economy. As Table 3.2 shows, this result is robust to all our specifications and is in line with Hypothesis 3.1 ('Bank Systemic Risk'). Note that this result holds for given bank characteristics such as asset risk, size, profitability, leverage, or loan growth. A financial institution of a country that experienced an excessive credit growth originates higher systemic risk than a bank with identical size or loan growth domiciled in a country with a credit provision close to its equilibrium credit path. Since we control for banks' asset risk, the result points towards an increase in the contribution to systemic risk due to exogenous factors as, for example, the economic context or an increasing asset correlation with other institutions arising from the behavior of competitor banks.

As a robustness check, we analyze whether the results hold if we consider only a short horizon of abnormal credit growth and if we consider a longer horizon of excessive credit. To this extent, we run the regression using the moving average of the credit gap over the past four quarters and the past twelve quarters, respectively. As Table 3.9 in Appendix 3.C shows, the effect of the credit gap is of a similar magnitude for a short-term excessive credit. However, an increase in the average credit gap over three years has

[11] As a robustness check, we provide the main results also with a narrower cluster level on the bank level.

Table 3.2: Baseline Regression Systemic Risk

VARIABLES	(1) $-\Delta CoVaR$	(2) $-\Delta CoVaR$	(3) $-\Delta CoVaR$	(4) $-\Delta CoVaR$
L.$-\Delta CoVaR$	0.86345***	0.88892***	0.85217***	1.00764***
	(0.02515)	(0.02530)	(0.02335)	(0.01583)
L2.$-\Delta CoVaR$	-0.18102***	-0.16133***	-0.18132***	-0.22699***
	(0.03045)	(0.04544)	(0.03285)	(0.04102)
L3.$-\Delta CoVaR$	-0.03390	-0.10884***	-0.03496	-0.09262***
	(0.02240)	(0.03165)	(0.02314)	(0.03583)
L4.$-\Delta CoVaR$	0.14548***	0.28922***	0.14265***	0.23550***
	(0.02057)	(0.03692)	(0.02029)	(0.02450)
Credit Gap	0.00145*	0.00406**	0.00163**	0.00528***
	(0.00073)	(0.00198)	(0.00071)	(0.00166)
L.$-VaR$			0.00228	-0.03970***
			(0.00707)	(0.00875)
L.log(Total Assets)			0.04477	0.01392*
			(0.02695)	(0.00756)
L.ROA			-0.00159	-0.02333**
			(0.00508)	(0.01037)
L.Leverage			0.00001	0.00012***
			(0.00002)	(0.00003)
L.Loan Growth			-0.10763**	-0.14311
			(0.05048)	(0.09215)
Constant	0.09184	0.04031	-0.77133	0.06503
	(0.08077)	(0.05209)	(0.62248)	(0.17044)
Observations	4,284	4,284	4,084	4,084
R-squared	0.82453		0.82194	
Number of Banks	127	127	122	122
Methodology	FE	GMM	FE	GMM
Test for AR(1) (p-value)		0.000		0.000
Test for AR(2) (p-value)		0.773		0.440
Hansen Test (p-value)		1.000		1.000

Regression results for Equation 3.5. The first and third column show results from an OLS regression using time and bank fixed effects. The second and fourth columns show the results of a system GMM estimation with time dummies. The credit gap variable and the VaR are treated as potentially endogenous. The instruments used are the fifth and the sixth lag of the dependent variable and the second and third lag of the credit gap and VaR (differenced equation) and $\Delta y_{i,t-4}, \Delta creditgap_{i,t-1}, \Delta VaR_{i,t-1}$ (level equation). All bank balance sheet variables are treated as predetermined such that these instruments are used only in the level equation. We choose the minimum lag structure of the instruments in order to mitigate a problem of weak instruments. AR(1) and AR(2) are tests for first-order and second-order serial correlation in the first-differenced residuals with the null of no serial correlation. Standard errors are clustered at the country level throughout (in parentheses). ***, **, * indicate significance at the 1%, 5% and 10% levels.

a stronger impact on the systemic risk contribution of banks resident in a credit booming country, as Table 3.11 in Appendix 3.D documents.

3.5.2 Is the Increase in Systemic Risk Exogenous?

In Section 3.5.1, we have shown that there is a positive correlation between excessive credit to the private sector and the systemic risk contribution of financial institutions domiciled in this economy. We now analyze in this section whether this result is driven by third factors that could have led to a spurious relationship between the two phenomena. More precisely, we investigate whether the increase in bank systemic risk is only due to exogenous factors as, for example, the general economic perspective or the level of asset prices, or whether excessive credit has an impact on systemic risk beyond these mechanisms. We show the results obtained by including, first independently and then jointly, our main proxies of the economic context in Table 3.3 (fixed effects regression) and Table 3.4 (system GMM).

3.5.2.1 General Economic Conditions and Perspectives

We analyze the general economic conditions and perspectives of an economy as a first potential channel that could yield to a spurious relation between credit growth and systemic risk. On the one hand, we would expect a positive correlation between excessive credit and economic growth if the credit provided to the private sector had been value enhancing. On the other hand, economic growth might also affect systemic risk through the channel of the economic context or through increasing asset correlation. We therefore rerun our analysis including the growth rate of GDP. We further look for a nonlinear effect of excessive credit on systemic risk, i.e. whether the effect of excessive credit depends on the growth rate of the GDP.[12]

Once we control for the general economic perspectives, the effect of the credit gap is found to be significant and positive when we apply the fixed effects methodology with a coefficient of similar magnitude compared to the baseline results in Table 3.2. However, we find a significant effect of the credit gap in the system GMM model only if we control for bank characteristics. Moreover, we observe for both methodologies fixed effects OLS and system GMM a positive and significant effect of the GDP growth, indicating that banks become more systemically relevant the faster the economic upswing is. Interestingly, we find a negative coefficient for the interaction term of the credit gap and the GDP growth, which indicates a diminishing effect of excessive credit on banks' contribution to systemic risk if the economy is doing well. However, once the economic perspectives reverse, systemic risk is higher if the provision of credit to the private sector was excessively large.

[12] In order to facilitate the interpretation of the credit gap coefficient, we demeaned the GDP growth in our regressions.

Table 3.3: Exogenous Factors of Systemic Risk - FE Regression

VARIABLES	(1) $-\Delta CoVaR$	(2) $-\Delta CoVaR$	(3) $-\Delta CoVaR$	(4) $-\Delta CoVaR$	(5) $-\Delta CoVaR$
L.$-\Delta CoVaR$	0.86324***	0.85488***	0.85829***	0.84739***	0.84982***
	(0.02336)	(0.02378)	(0.02381)	(0.02247)	(0.02303)
L2.$-\Delta CoVaR$	-0.17912***	-0.17973***	-0.18106***	-0.18128***	-0.17959***
	(0.03043)	(0.03297)	(0.03020)	(0.03270)	(0.03283)
L3.$-\Delta CoVaR$	-0.03219	-0.03327	-0.03463	-0.03514	-0.03333
	(0.02326)	(0.02417)	(0.02206)	(0.02296)	(0.02407)
L4.$-\Delta CoVaR$	0.14492***	0.14194***	0.14584***	0.14381***	0.14296***
	(0.01990)	(0.01955)	(0.02160)	(0.02090)	(0.02019)
Credit Gap	0.00126*	0.00146*	0.00091**	0.00115**	0.00089**
	(0.00072)	(0.00071)	(0.00040)	(0.00041)	(0.00039)
GDP Growth	1.69585**	1.74788**			1.92563**
	(0.78304)	(0.75723)			(0.88049)
GDP Growth · Credit Gap	-0.05079**	-0.04916**			-0.05391**
	(0.02338)	(0.01934)			(0.01920)
Housepriceindex			0.00135**	0.00114**	0.00129**
			(0.00051)	(0.00049)	(0.00056)
Housepriceindex · Credit Gap			-0.00002**	-0.00002*	-0.00002*
			(0.00001)	(0.00001)	(0.00001)
L.$-VaR$		0.00134		0.00288	0.00188
		(0.00653)		(0.00664)	(0.00609)
L.log(Total Assets)		0.03976		0.04025	0.03410
		(0.02554)		(0.02354)	(0.02208)
L.ROA		-0.00449		-0.00146	-0.00466
		(0.00490)		(0.00541)	(0.00518)
L.Leverage		0.00000		0.00001	0.00001
		(0.00002)		(0.00002)	(0.00002)
L.Loan Growth		-0.10590**		-0.10138*	-0.09827*
		(0.04876)		(0.05233)	(0.05099)
Constant	0.12237	-0.63592	0.11048	-0.67462	-0.51175
	(0.07288)	(0.57766)	(0.07989)	(0.55419)	(0.50604)
Observations	4,284	4,084	4,284	4,084	4,084
R-squared	0.82542	0.82284	0.82550	0.82262	0.82370
Number of Banks	127	122	127	122	122
Methodology	FE	FE	FE	FE	FE

Regression results for Equation 3.5. All columns show the results of an OLS regression with time and bank fixed effects. The variables GDP growth and Housepriceindex are demeaned. Standard errors are clustered at the country level throughout (in parentheses). ***, **, * indicate significance at the 1%, 5% and 10% levels.

3.5.2.2 Real Estate Boom

We next investigate whether an asset price boom in the housing market could yield to a spurious relation between credit growth and bank systemic risk. Households often provide their property as collateral when applying for a real estate loan such that the level of house prices could be positively correlated with the provision of credit. Moreover, as history has shown, a strong increase in house prices is often related to distress in the financial system, especially when the price increase is due to an asset price bubble (see Brunnermeier and Schnabel (2015)).[13] Similar to the economic perspectives, we analyze again the nonlinear effects of excessive credit on systemic risk with regard to an asset

[13]Note that we use an index of house prices that is normalized to 100 for the year 2000 such that a high level of the index is associated with a strong increase in property prices since 2000.

price boom and investigate whether the effect of excessive credit depends on the level of house prices.[14]

Table 3.4: Exogenous Factors of Systemic Risk - system GMM

VARIABLES	(1) $-\Delta CoVaR$	(2) $-\Delta CoVaR$	(3) $-\Delta CoVaR$	(4) $-\Delta CoVaR$	(5) $-\Delta CoVaR$
L.$-\Delta CoVaR$	0.90576***	0.99163***	0.91956***	1.00042***	0.98541***
	(0.03107)	(0.02344)	(0.03380)	(0.02811)	(0.02775)
L2.$-\Delta CoVaR$	-0.15849***	-0.20616***	-0.17371***	-0.22322***	-0.20843***
	(0.04578)	(0.04355)	(0.04953)	(0.04214)	(0.04038)
L3.$-\Delta CoVaR$	-0.10564***	-0.08607**	-0.09761***	-0.07088*	-0.06378
	(0.03734)	(0.03788)	(0.03701)	(0.04156)	(0.03909)
L4.$-\Delta CoVaR$	0.26586***	0.22225***	0.25169***	0.20448***	0.19560***
	(0.03220)	(0.02449)	(0.03909)	(0.03220)	(0.02906)
Credit Gap	0.00076	0.00258***	0.00100	0.00189***	0.00134***
	(0.00094)	(0.00094)	(0.00077)	(0.00048)	(0.00045)
GDP Growth	2.54019***	2.21112**			1.74907***
	(0.95646)	(0.89577)			(0.67716)
GDP Growth · Credit Gap	-0.05479***	-0.06940***			-0.07204***
	(0.01723)	(0.02152)			(0.02129)
Housepriceindex			0.00026**	0.00062***	0.00059***
			(0.00011)	(0.00014)	(0.00016)
Housepriceindex · Credit Gap			-0.00002	-0.00003	-0.00002*
			(0.00002)	(0.00002)	(0.00001)
L.$-VaR$		-0.03281***		-0.03152***	-0.02977***
		(0.00591)		(0.00686)	(0.00474)
L.log(Total Assets)		0.01357**		0.00937	0.00783
		(0.00638)		(0.00721)	(0.00663)
L.ROA		-0.02015**		-0.01789**	-0.01949***
		(0.00860)		(0.00894)	(0.00745)
L.Leverage		0.00009***		0.00008***	0.00007***
		(0.00001)		(0.00002)	(0.00001)
L.Loan Growth		-0.14074*		-0.17732*	-0.16743*
		(0.08161)		(0.10059)	(0.08706)
Constant	0.03140	0.04168	-0.09323	0.13862	0.16366
	(0.03439)	(0.18042)	(0.06156)	(0.12456)	(0.13319)
Observations	4,284	4,084	4,284	4,084	4,084
Number of Banks	127	122	127	122	122
Methodology	GMM	GMM	GMM	GMM	GMM
Test for AR(1) (p-value)	0.000	0.000	0.000	0.000	0.000
Test for AR(2) (p-value)	0.753	0.601	0.881	0.412	0.417
Hansen Test (p-value)	1.000	1.000	1.000	1.000	1.000

Regression results for Equation 3.5. All columns show the results of a system GMM estimation with time dummies. The credit gap variable, the VaR, the GDP growth, and the interaction term are treated as potentially endogenous. The instruments used are the fifth and the sixth lag of the dependent variable and the second and third lag of the credit gap, the VaR, the GDP growth, and the interaction term (differenced equation) and $\Delta y_{i,t-4}, \Delta creditgap_{i,t-1}, \Delta VaR_{i,t-1}, \Delta GDPgrowth_{i,t-1}, and \Delta (creditgap \cdot GDPgrowth)_{i,t-1}$ (level equation). All bank balance sheet variables are treated as predetermined such that these instruments are used only in the level equation. We choose the minimum lag structure of the instruments in order to mitigate a problem of weak instruments. AR(1) and AR(2) are tests for first-order and second-order serial correlation in the first-differenced residuals with the null of no serial correlation. The variables GDP growth and Housepriceindex are demeaned. Standard errors are clustered at the country level throughout (in parentheses). ***, **, * indicate significance at the 1%, 5% and 10% levels.

The results regarding the effect of excessive credit are again mixed. While the fixed effects regression in Table 3.3 confirms the positive and significant effect of the credit gap,

[14] Again, we demeaned the house price index in our regressions in order to facilitate the interpretation of the credit gap coefficient.

the system GMM estimation in Table 3.4 does only if we control for bank characteristics, which is mainly due to an increase in standard errors rather than a decrease in the point estimate. The effect of the house price index, too, is found to have a significant effect on bank systemic risk with the expected positive sign, which indicates that banks' contribution to systemic risk is particularly large in times of high domestic property prices. We observe a negative and significant effect of the interaction term in almost all specifications, and interpret this finding as bank systemic risk being particularly high in countries where not only the credit provision to the private sector is large, but also where excessive credit is accompanied by low real estate prices.

We find thus evidence for both Hypothesis 2a ('Economic Context and Systemic Risk') and Hypothesis 2b ('Credit Gap and Economic Context') for both variables determining the economic context GDP growth and property price developments.

3.5.3 Excessive Credit and Asset Risk

The previous section has shown that excessive credit has an impact on banks' contribution to systemic risk. While this correlation is partly driven by variables determining the economic context, we also find some evidence for an additional effect arising from the credit gap. We now investigate the relationship between banks' asset risk and excessive credit, and thus, whether financial institutions respond to increasing credit provision to the private sector by changing the asset quality of their portfolios. Thus, beside the exogenously driven increase in systemic risk, we want to analyze whether banks endogenously choose assets with higher risk. The results are shown in Table 3.5 in a similar manner as in Table 3.2 before: Column one and column three display the results from the fixed effects regression with and without bank controls, while column two and column four document the results of excessive credit on bank asset risk of an Arellano and Bover (1995)/Blundell and Bond (1998)-type linear dynamic panel estimation.

We find evidence for a positive correlation between the average credit-to-GDP gap over the past two years and the value at risk for financial institutions residing in the credit booming economy. This finding regarding the positive and highly significant effect of excessive credit is robust across all our specifications and gives reason to assume that banks domiciled in credit booming economies actively adjust the riskiness of their assets. Note that the positive correlation remains significant even if we control for bank balance sheet variables such as bank size, leverage, return, or loan growth. Thus, a financial institution with similar characteristics indicates higher asset risk if it is domiciled in a country where the private sector is borrowing to an unusually high degree compared to the long-term trend. This result is in line with Hypothesis 3 ('Bank Asset Risk'). Not

Table 3.5: Excessive Credit and Asset Risk

VARIABLES	(1) $-VaR$	(2) $-VaR$	(3) $-VaR$	(4) $-VaR$
L.$-VaR$	0.83338***	0.76944***	0.81308***	0.70097***
	(0.05335)	(0.08740)	(0.05594)	(0.10442)
L2.$-VaR$	-0.16128***	-0.19436***	-0.16106***	-0.17509***
	(0.05040)	(0.05998)	(0.04992)	(0.06255)
L3.$-VaR$	-0.03292	-0.10829**	-0.04086	-0.11164**
	(0.02538)	(0.04341)	(0.02533)	(0.05272)
L4.$-VaR$	0.13511***	0.25644***	0.13427***	0.21476***
	(0.02194)	(0.03873)	(0.02369)	(0.05304)
Credit Gap	0.00996**	0.02433***	0.01191***	0.02778***
	(0.00374)	(0.00793)	(0.00386)	(0.00874)
L.log(Total Assets)			0.47645***	0.09657**
			(0.11267)	(0.04240)
L.ROA			-0.14124***	-0.28251**
			(0.03999)	(0.12643)
L.Leverage			-0.00019**	0.00097**
			(0.00008)	(0.00046)
L.Loan Growth			-0.48328	-0.23120
			(0.32128)	(0.53998)
Constant	0.10899	1.78650***	-8.63336***	0.74082
	(0.63958)	(0.60010)	(2.63071)	(0.60882)
Observations	4,284	4,284	4,084	4,084
R-squared	0.87124		0.86999	
Number of Banks	127	127	122	122
Methodology	FE	GMM	FE	GMM
Test for AR(1) (p-value)		0.000		0.000
Test for AR(2) (p-value)		0.733		0.881
Hansen Test (p-value)		1.000		1.000

Regression results for Equation 3.5. The first and third column show results from an OLS regression using time and bank fixed effects. The second and fourth columns show the results of a system GMM estimation with time dummies. The credit gap variable is treated as potentially endogenous. The instruments used are the fifth and the sixth lag of the dependent variable and the second and third lag of the credit gap (differenced equation) and $\Delta y_{i,t-4}, \Delta creditgap_{i,t-1}$ (level equation). All bank balance sheet variables are treated as predetermined such that these instruments are used only in the level equation. We choose the minimum lag structure of the instruments in order to mitigate a problem of weak instruments. AR(1) and AR(2) are tests for first-order and second-order serial correlation in the first-differenced residuals with the null of no serial correlation. Standard errors are clustered at the country level throughout (in parentheses). ***, **, * indicate significance at the 1%, 5% and 10% levels.

only are the banks that have experienced a large growth in lending loosening their credit standards, but banks resident in the credit booming economy are choosing, on average, a higher asset risk. The coefficients regarding the control variables are also largely as expected. Banks that realized a larger return in the previous period indicate lower risk in the current period. Moreover, larger banks indicate a higher level of risk, which might reflect moral hazard due to implicit bailout guarantees.

Similar to the analysis of banks' systemic risk, we run a robustness check on all regressions using a measure of excessive credit with a shorter horizon and a measure of excessive credit with a longer horizon. We use the average credit-to-GDP gap over the past four quarters and the average credit-to-GDP gap over the past twelve quarters, respectively. The results of the short-term focus of excessive credit in Table 3.10 in Appendix 3.C document that the effect of the credit-to-GDP gap on bank asset risk is quantitatively slightly smaller, while it is of similar magnitude for an increase in the three-year average of the credit-to-GDP gap, as it is documented in Table 3.12 in Appendix 3.D.

3.5.4 Is the Increase in Asset Risk Exogenous?

One might argue that not only systemic risk is driven by the economic context, but also the positive correlation between the credit gap and bank asset risk could be due to exogenous factors. We therefore analyze in this section whether bank asset risk is purely driven by general economic perspectives or the level of property prices, or whether there is additional explanatory power in the credit-to-GDP gap that might result, for example, from a change in banks' risk culture. We show the results obtained by including, first independently and then jointly, our main proxies of the economic context in the growth rate of the GDP and in an index of real estate prices, respectively, in Table 3.6 (fixed effects regression) and Table 3.7 (system GMM).

Regarding the economic context variables, we find no effect for the speed of economic growth on bank asset risk. The index of property prices, however, displays a positive and significant coefficient, which indicates that banks domiciled in countries with higher property prices show on average higher asset risk. Most importantly, our main variable of interest, the credit-to-GDP gap, remains significant with a point estimate that is of very similar magnitude to the baseline regression in Table 3.5. This result holds true for both methodologies fixed effects regression as well as system GMM. Bank asset risk is not only driven by exogenous factors, but there is an additional effect of excessive credit on bank asset risk that cannot be explained by the economic context. We interpret this result as some evidence for a change in bank's risk attitude. Taking the excessive provision of credit as increasing competition, our findings would be in line with the theoretical suggestions of Rajan (1994) and Aikman, Haldane, and Nelson (2015). Bank managers might fear that competitor banks make large profits in credit booming times. Thus, they choose endogenously assets with a higher risk-return structure due to their private incentive to *"keeping up with the Goldmans"*.

Table 3.6: Exogenous Factors of Asset Risk - FE Regression

VARIABLES	(1) $-VaR$	(2) $-VaR$	(3) $-VaR$	(4) $-VaR$	(5) $-VaR$
L.$-VaR$	0.82907***	0.80914***	0.82547***	0.80654***	0.80266***
	(0.05058)	(0.05227)	(0.04880)	(0.05240)	(0.04869)
L2.$-VaR$	-0.16412***	-0.16403***	-0.16074***	-0.16042***	-0.16320***
	(0.05118)	(0.05111)	(0.04979)	(0.04946)	(0.05053)
L3.$-VaR$	-0.03240	-0.03979	-0.03407	-0.04172	-0.03998
	(0.02858)	(0.02803)	(0.02476)	(0.02477)	(0.02773)
L4.$-VaR$	0.13709***	0.13506***	0.13848***	0.13778***	0.13913***
	(0.02030)	(0.02189)	(0.02386)	(0.02616)	(0.02420)
Credit Gap	0.00927**	0.01110***	0.00717**	0.00904***	0.00779***
	(0.00363)	(0.00376)	(0.00287)	(0.00266)	(0.00243)
GDP Growth	3.27528	4.95224			6.54147
	(5.52760)	(5.40612)			(6.14922)
GDP Growth · Credit Gap	-0.31324*	-0.32327**			-0.34640**
	(0.15087)	(0.15276)			(0.15725)
Housepriceindex			0.00794***	0.00778***	0.00847***
			(0.00248)	(0.00219)	(0.00250)
Housepriceindex · Credit Gap			-0.00007	-0.00007	-0.00009
			(0.00008)	(0.00008)	(0.00007)
L.log(Total Assets)		0.44276***		0.44076***	0.40306***
		(0.10695)		(0.08248)	(0.07561)
L.ROA		-0.14834***		-0.14310***	-0.15230***
		(0.03818)		(0.03459)	(0.03256)
L.Leverage		-0.00021**		-0.00016**	-0.00018**
		(0.00008)		(0.00007)	(0.00007)
L.Loan Growth		-0.47070		-0.39935	-0.38500
		(0.31164)		(0.30397)	(0.29947)
Constant	0.22084	-7.83680***	0.18741	-7.88790***	-6.97972***
	(0.52888)	(2.41783)	(0.57351)	(2.01879)	(1.76205)
Observations	4,284	4,084	4,284	4,084	4,084
R-squared	0.87206	0.87086	0.87248	0.87110	0.87210
Number of Banks	127	122	127	122	122
Methodology	FE	FE	FE	FE	FE

Regression results for Equation 3.5. All columns show the results of an OLS regression with time and bank fixed effects. The variables GDP growth and Housepriceindex are demeaned. Standard errors are clustered at the country level throughout (in parentheses). ***, **, * indicate significance at the 1%, 5% and 10% levels.

3.6 Conclusion

Previous literature has found that the credit-to-GDP gap is the best single leading indicator for the buildup phase of financial crises within a three-year horizon (Drehmann, Borio, and Tsatsaronis (2011)) or for systemic banking crises using an evaluation period that lasts from five years to one year prior to a crisis (Detken, Weeken, Lucia, Bonfim, Boucinha, Castro, Frontczak, Giordana, Giese, Jahn, Kakes, Klaus, Lang, Puzanova, and Welz (2014)). We analyze in this chapter the causes behind this finding and investigate two important types of bank risk in times of abnormal credit provision.

Past papers illustrate that a large credit gap is a good indicator of financial distress because an increase in loans on the bank level is associated with a decrease in lending standards. This chapter of the thesis goes one step further and investigates bank-specific

Table 3.7: Exogenous Factors of Asset Risk - system GMM

VARIABLES	(1) $-VaR$	(2) $-VaR$	(3) $-VaR$	(4) $-VaR$	(5) $-VaR$
L.$-VaR$	0.82240***	0.77959***	0.85997***	0.81019***	0.82775***
	(0.07062)	(0.07686)	(0.07123)	(0.08121)	(0.06809)
L2.$-VaR$	-0.21709***	-0.21326***	-0.22246***	-0.20920***	-0.19950***
	(0.06254)	(0.06349)	(0.06810)	(0.07131)	(0.07590)
L3.$-VaR$	-0.07709**	-0.07664	-0.07373*	-0.07710*	-0.07100*
	(0.03931)	(0.04823)	(0.04093)	(0.04182)	(0.04238)
L4.$-VaR$	0.24139***	0.20722***	0.21026***	0.18011***	0.18154***
	(0.02604)	(0.03710)	(0.03344)	(0.02641)	(0.02819)
Credit Gap	0.01882***	0.02312***	0.01397**	0.01725***	0.01428***
	(0.00513)	(0.00545)	(0.00577)	(0.00587)	(0.00365)
GDP Growth	2.75780	5.52332			5.22991
	(5.81442)	(6.27181)			(4.90051)
GDP Growth · Credit Gap	-0.35298**	-0.41814**			-0.39883**
	(0.17678)	(0.19294)			(0.16513)
Housepriceindex			0.00153	0.00223	0.00182*
			(0.00130)	(0.00146)	(0.00108)
Housepriceindex · Credit Gap			0.00008	0.00003	-0.00002
			(0.00013)	(0.00014)	(0.00011)
L.log(Total Assets)		0.07059**		0.05860*	0.04627
		(0.03411)		(0.03426)	(0.03183)
L.ROA		-0.23969***		-0.22863***	-0.21392***
		(0.07724)		(0.07792)	(0.06345)
L.Leverage		0.00071*		0.00073**	0.00057*
		(0.00038)		(0.00030)	(0.00030)
L.Loan Growth		-0.14645		-0.33354	-0.24529
		(0.45383)		(0.50364)	(0.44868)
Constant	1.25281***	0.84829	-0.23816	-0.49962	0.93844*
	(0.25997)	(0.53184)	(0.69730)	(1.16109)	(0.53006)
Observations	4,284	4,084	4,284	4,084	4,084
Number of Banks	127	122	127	122	122
Methodology	GMM	GMM	GMM	GMM	GMM
Test for AR(1) (p-value)	0.000	0.000	0.000	0.000	0.000
Test for AR(2) (p-value)	0.463	0.508	0.473	0.570	0.666
Hansen Test (p-value)	1.000	1.000	1.000	1.000	1.000

Regression results for Equation 3.5. All columns show the results of a system GMM estimation with time dummies. The credit gap variable, the GDP growth, and the interaction term are treated as potentially endogenous. The instruments used are the fifth and the sixth lag of the dependent variable and the second and third lag of the credit gap, the GDP growth, and the interaction term (differenced equation) and $\Delta y_{i,t-4}, \Delta creditgap_{i,t-1}, \Delta GDPgrowth_{i,t-1}, and \Delta(creditgap \cdot GDPgrowth)_{i,t-1}$ (level equation). All bank balance sheet variables are treated as predetermined such that these instruments are used only in the level equation. We choose the minimum lag structure of the instruments in order to mitigate a problem of weak instruments. AR(1) and AR(2) are tests for first-order and second-order serial correlation in the first-differenced residuals with the null of no serial correlation. The variables GDP growth and Housepriceindex are demeaned. Standard errors are clustered at the country level throughout (in parentheses). ***, **, * indicate significance at the 1%, 5% and 10% levels.

behavior in times of an economy-wide credit boom rather the implications from a lending boom at the bank level. We test for both exogenous factors driving banks' risk as well as changing bank behavior in a credit booming economy. More precisely, we analyze whether banks domiciled in countries with excessive credit to the private sector, as measured by the credit-to-GDP gap described in the Basel III regulatory framework, contribute more significantly to systemic risk than their peers in other countries. We further investigate whether this correlation is purely driven by exogenous factors or whether there exists additional channels through which excessive credit could amplify banks' contribution to systemic risk. Finally, we analyze whether banks resident in credit booming economies flag higher asset risk, and whether this increase in bank asset risk is purely driven by the economic context.

We find a positive correlation between excessive credit to the private sector and bank systemic risk, which implies that banks in countries with excessive credit growth contribute on average more to the systemic risk ceteris paribus bank characteristics, as for example the bank-specific loan growth, bank size, asset risk and return, or leverage. When looking for potential channels that might cause a spurious relation between excessive borrowing of the private sector and systemic risk, we detect strong evidence of a higher contribution to systemic risk for institutions in fast growing economies and weaker evidence for high systemic risk in institutions domiciled in countries with high property prices. While these factors influence systemic risk through the economic context, we still find weak evidence of an additional effect of excessive credit on systemic risk outside these channels. More precisely, we observe that a large credit-to-GDP gap yields a higher contribution to systemic risk for banks in countries with weak economic conditions and low house prices. Finally, we find a positive relationship between the credit-to-GDP gap and the asset risk of banks domiciled in credit booming countries. Note that this result again holds for given bank characteristics as, for example, bank loan growth, bank size, or bank leverage, and remains strongly significant once we control for the economic context.

Interpreting excessive credit as an indicator of strong competition, our findings would be in line with the theoretical suggestions of Rajan (1994) and Aikman, Haldane, and Nelson (2015). Bank managers might fear that competitor banks make large profits in times of a credit boom and thus choose endogenous assets with a higher risk-return structure in order to *"keep up with the Goldmans"*.

Regarding policy implications, our finding on an exogenous increase in banks' contribution to systemic risk in times of excessive credit provides a micro-founded justification for the introduction of the macro-prudential instrument of countercyclical capital buffers, and for its design based on the credit-to-GDP gap. However, policy makers should be reminded that the probability of a financial crisis in times of excessive credit may not only result from an increase in systemic risk, but that there might also be a change in banks' attitudes toward risk. This rise in banks' asset risk, which might result, for example, from competitive pressure or a limited number of good borrowers, in combination with a high contribution to systemic risk makes the financial system particularly vulnerable. Therefore, in addition to the usage of a countercyclical capital buffer as a macro-prudential policy tool, the micro-prudential regulation needs to monitor carefully the risk attitudes of all banks within an economy that displays a large credit-to-GDP gap.

Appendix

3.A Estimation of CoVaR

We now briefly explain how to estimate CoVaR,[15] which is defined as follows:

$$CoVaR_q^{(system|i)} = VaR_q^{system}|VaR_q^i \tag{3.6}$$

The variable, on which the calculation of VaR and $CoVaR$ is based, X^i, is in our case the return of market-valued total assets. Following closely the procedure proposed by Adrian and Brunnermeier (2011), we estimate $CoVaR$ by using quantile regression, using a stress level of 1%.

We use the extended version of $CoVaR$ that models the time variation of the joint distribution of asset returns as a function of a number of state variables. We first generate VaR^i by regressing X^i on the lagged state variables, M_{t-1}, in a quantile regression and generating predicted values:

$$VaR_t^i(q) = \hat{\alpha}_q^i + \hat{\gamma}_q^i M_{t-1} \tag{3.7}$$

Then we regress X^{system} on individual returns, X^i, and the lagged state variables, M_{t-1}, in a quantile regression at the 1% level, and generate predicted values at VaR_q^i:

$$CoVaR_t^i(q) = \hat{\alpha}_{1\%}^{system|i} + \hat{\beta}_{1\%}^{system|i} VaR_t^i(q) + \hat{\gamma}_{1\%}^{system|i} M_{t-1} \tag{3.8}$$

In the definition of our variables, we closely follow Adrian and Brunnermeier (2011). X^i, is the growth rate of market-valued total assets. Market equity is taken from Thomson Reuters Datastream and the leverage from Bureau van Dijk's Bankscope. Furthermore, we use the same vector of lagged state variables as Adrian and Brunnermeier, but exclude

[15]This exposition closely follows Adrian and Brunnermeier (2011).

the real estate sector return in excess of the market return because this variable is not available for the full set of countries. Our measure of systemic risk, $\Delta CoVaR_t^i$, is defined as the difference between $CoVaR^i$ conditioned on distress times versus normal times of bank i, where normal times are characterized by the median. Hence, it is calculated as follows, using again the 1% stress level:

$$\begin{aligned} \Delta CoVaR_t^i(1\%) &= CoVaR_t^i(1\%) - CoVaR_t^i(50\%) \\ &= \hat{\beta}_{1\%}^{system|i}(VaR_t^i(1\%) - VaR_t^i(50\%)) \end{aligned} \tag{3.9}$$

From these regressions, we obtain a panel of daily $\Delta CoVaR_t^i$, measuring the risk contribution of each individual institutions to the system. Note that $\Delta CoVaR_t^i$ is typically negative, with a more negative value indicating a greater contribution to systemic risk. For the ease of interpretation, we use $-\Delta CoVaR_t^i$ throughout the chapter, implying that an increase in this variable is to be interpreted as an increase in the contribution to systemic risk.

3.B List of Countries and Banks in the Sample

Table 3.8

Austria	Erste Group Bank AG	**Netherlands**	Delta Lloyd NV
Belgium	Dexia		ING Groep NV
	KBC Groep NV	**Norway**	DnB ASA
Denmark	Danske Bank A/S		Storebrand Group
Finland	Sampo Plc	**Portugal**	Banco BPI SA
France	BNP Paribas		Banco Comercial Português, SA
	Caisse Régionale du Languedoc		Banco Espirito Santo SA
	Crédit Agricole S.A.	**Spain**	Banco Bilbao Vizcaya Argentaria SA
	Crédit Industriel et Commercial		Banco Popular Espanol SA
	Natixis		Banco Santander SA
	Société Générale		Banco de Sabadell SA
Germany	Aareal Bank AG		Caixabank, S.A.
	Commerzbank AG	**Sweden**	Nordea Bank AB
	Deutsche Bank AG		Skandinaviska Enskilda Banken AB
	Deutsche Postbank AG		Svenska Handelsbanken
	IKB Deutsche Industriebank AG		Swedbank AB
	Wüstenrot & Württembergische	**Switzerland**	Banque Cantonale Vaudoise
Greece	Alpha Bank AE		Credit Suisse Group AG
	Eurobank Ergasias SA		Julius Baer Group Ltd
	National Bank of Greece SA		Swiss Life Holding
	Allied Irish Banks plc		UBS AG
Ireland	Bank of Ireland	**United Kingdom**	Barclays Plc
Italy	Banca Monte dei Paschi di Siena SpA		HSBC Holdings Plc
	Banca Popolare di Milano SCaRL		ICAP Plc
	Banca popolare dell'Emilia Romagna		Lloyds Banking Group Plc
	Banco Popolare		Royal Bank of Scotland Group Plc (The)
	Intesa Sanpaolo		Standard Chartered Plc
	Mediobanca SpA	**United States**	Annaly Capital Management Inc
	UniCredit SpA		BB&T Corporation
	Unione di Banche Italiane Scpa		Bank of America Corporation
Japan	Aozora Bank Ltd		Bank of New York Mellon Corporation
	Bank of Kyoto		BlackRock, Inc
	Century Tokyo Leasing Corporation		CIT Group, Inc
	Chiba Bank Ltd.		CME Group Inc
	Daiwa Securities Group Inc		Capital One Financial Corporation
	Fukuoka Financial Group Inc		Charles Schwab Corporation
	Hachijuni Bank		Citigroup Inc
	Hiroshima Bank Ltd		Comerica Incorporated
	Hokuhoku Financial Group Inc.		Discover Financial Services
	Hyakugo Bank Ltd.		Fannie Mae
	Hyakujushi Bank Ltd.		Fifth Third Bancorp
	Iyo Bank Ltd		Freddie Mac
	Joyo Bank Ltd.		Goldman Sachs Group, Inc
	Mitsubishi UFJ Financial Group Inc		Huntington Bancshares Inc
	Mizuho Financial Group		JP Morgan Chase & Co.
	Nomura Holdings Inc		KeyCorp
	Orient Corporation		M&T Bank Corporation
	Orix Corporation		Metlife, Inc.
	Resona Holdings, Inc		Morgan Stanley
	San-In Godo Bank, Ltd		Northern Trust Corporation
	Senshu Ikeda Holdings Inc		PNC Financial Services Group Inc
	Shinkin Central Bank		Popular, Inc
	Shinsei Bank Limited		Prudential Financial Inc
	Shizuoka Bank		Regions Financial Corporation
	Sony Financial Holdings, Inc		SLM Corporation-Sallie Mae
	Sumitomo Mitsui Financial Group, Inc		State Street Corporation
	Sumitomo Mitsui Trust Holdings, Inc		SunTrust Banks, Inc.
	The 77 Bank		US Bancorp
	The Bank of Yokohama, Ltd		Wells Fargo & Company
	The Chugoku Bank, Ltd		Zions Bancorporation
	The Daishi Bank Ltd		
	The Gunma Bank Ltd		
	The Juroku Bank Ltd		
	The Nanto Bank Ltd		
	The Nishi-Nippon City Bank Ltd		
	The Shiga Bank, Ltd		
	Yamaguchi Financial Group, Inc		

3.C Credit Gap over One Year

3.C.1 Conditional Value at Risk

Table 3.9: Robustness Systemic Risk - moving average of the credit gap over 4 quarters

VARIABLES	(1) $-\Delta CoVaR$	(2) $-\Delta CoVaR$	(3) $-\Delta CoVaR$	(4) $-\Delta CoVaR$
L.$-\Delta CoVaR$	0.86386***	0.88247***	0.85226***	0.99721***
	(0.02527)	(0.02191)	(0.02325)	(0.01682)
L2.$-\Delta CoVaR$	-0.18081***	-0.15088***	-0.18108***	-0.21439***
	(0.03030)	(0.04495)	(0.03267)	(0.04183)
L3.$-\Delta CoVaR$	-0.03367	-0.11747***	-0.03467	-0.09682***
	(0.02250)	(0.02959)	(0.02325)	(0.03567)
L4.$-\Delta CoVaR$	0.14540***	0.30189***	0.14254***	0.24544***
	(0.02123)	(0.03636)	(0.02095)	(0.02491)
Credit Gap (1Y)	0.00127	0.00525**	0.00145*	0.00505***
	(0.00075)	(0.00246)	(0.00073)	(0.00165)
L.$-VaR$			0.00244	-0.03710***
			(0.00707)	(0.00826)
L.log(Total Assets)			0.04489	0.01387**
			(0.02770)	(0.00677)
L.ROA			-0.00193	-0.02263**
			(0.00489)	(0.00956)
L.Leverage			0.00001	0.00012***
			(0.00002)	(0.00003)
L.Loan Growth			-0.10795**	-0.13211
			(0.05062)	(0.08884)
Constant	0.08830	0.04087	-0.77944	0.01454
	(0.08165)	(0.06195)	(0.63716)	(0.16106)
Observations	4,284	4,284	4,084	4,084
R-squared	0.82444		0.82184	
Number of Banks	127	127	122	122
Methodology	FE	GMM	FE	GMM
Test for AR(1) (p-value)		0.000		0.000
Test for AR(2) (p-value)		0.642		0.587
Hansen Test (p-value)		1.000		1.000

Regression results for Equation 3.5. The first and third column show results from an OLS regression using time and bank fixed effects. The second and fourth columns show the results of a system GMM estimation with time dummies. The credit gap variable and the VaR are treated as potentially endogenous. The instruments used are the fifth and the sixth lag of the dependent variable and the second and third lag of the credit gap and VaR (differenced equation) and $\Delta y_{i,t-4}, \Delta creditgap_{i,t-1}, \Delta VaR_{i,t-1}$ (level equation). All bank balance sheet variables are treated as predetermined such that these instruments are used only in the level equation. We choose the minimum lag structure of the instruments in order to mitigate a problem of weak instruments. AR(1) and AR(2) are tests for first-order and second-order serial correlation in the first-differenced residuals with the null of no serial correlation. Standard errors are clustered at the country level throughout (in parentheses). ***, **, * indicate significance at the 1%, 5% and 10% levels.

3.C.2 Value at Risk

Table 3.10: Robustness Asset Risk - moving average of the credit gap over 4 quarters

	(1)	(2)	(3)	(4)
VARIABLES	$-VaR$	$-VaR$	$-VaR$	$-VaR$
L.$-VaR$	0.83340***	0.77141***	0.81280***	0.70309***
	(0.05372)	(0.07778)	(0.05629)	(0.09617)
L2.$-VaR$	-0.16057***	-0.18559***	-0.16022***	-0.17016***
	(0.05006)	(0.05409)	(0.04952)	(0.05695)
L3.$-VaR$	-0.03265	-0.12151***	-0.04063	-0.11882**
	(0.02550)	(0.04351)	(0.02541)	(0.05392)
L4.$-VaR$	0.13679***	0.28689***	0.13629***	0.24559***
	(0.02288)	(0.03588)	(0.02478)	(0.05104)
Credit Gap (1Y)	0.00962**	0.02682***	0.01167***	0.02756***
	(0.00374)	(0.00757)	(0.00381)	(0.00712)
L.log(Total Assets)			0.48045***	0.09383**
			(0.10613)	(0.04085)
L.ROA			-0.14390***	-0.26943**
			(0.03897)	(0.11806)
L.Leverage			-0.00018**	0.00088**
			(0.00008)	(0.00043)
L.Loan Growth			-0.48240	-0.11265
			(0.32451)	(0.48214)
Constant	0.06745	1.50321***	-8.75685***	-0.28250
	(0.63963)	(0.53553)	(2.52577)	(1.32996)
Observations	4,284	4,284	4,084	4,084
R-squared	0.87130		0.87012	
Number of Banks	127	127	122	122
Methodology	FE	GMM	FE	GMM
Test for AR(1) (p-value)		0.000		0.000
Test for AR(2) (p-value)		0.853		0.930
Hansen Test (p-value)		1.000		1.000

Regression results for Equation 3.5. The first and third column show results from an OLS regression using time and bank fixed effects. The second and fourth columns show the results of a system GMM estimation with time dummies. The credit gap variable is treated as potentially endogenous. The instruments used are the fifth and the sixth lag of the dependent variable and the second and third lag of the credit gap (differenced equation) and $\Delta y_{i,t-4}, \Delta creditgap_{i,t-1}$ (level equation). All bank balance sheet variables are treated as predetermined such that these instruments are used only in the level equation. We choose the minimum lag structure of the instruments in order to mitigate a problem of weak instruments. AR(1) and AR(2) are tests for first-order and second-order serial correlation in the first-differenced residuals with the null of no serial correlation. Standard errors are clustered at the country level throughout (in parentheses). ***, **, * indicate significance at the 1%, 5% and 10% levels.

3.D Credit Gap over Three Years

3.D.1 Conditional Value at Risk

Table 3.11: Robustness Systemic Risk - moving average of the credit gap over 12 quarters

VARIABLES	(1) $-\Delta CoVaR$	(2) $-\Delta CoVaR$	(3) $-\Delta CoVaR$	(4) $-\Delta CoVaR$
L.$-\Delta CoVaR$	0.86327***	0.88874***	0.85190***	1.01126***
	(0.02497)	(0.02671)	(0.02330)	(0.01489)
L2.$-\Delta CoVaR$	-0.18101***	-0.15782***	-0.18134***	-0.23040***
	(0.03047)	(0.04475)	(0.03291)	(0.04162)
L3.$-\Delta CoVaR$	-0.03400	-0.10908***	-0.03503	-0.08823**
	(0.02236)	(0.03314)	(0.02309)	(0.03630)
L4.$-\Delta CoVaR$	0.14526***	0.27728***	0.14234***	0.22487***
	(0.02015)	(0.03970)	(0.01986)	(0.02434)
Credit Gap (1Y)	0.00159*	0.00472**	0.00178**	0.00612***
	(0.00076)	(0.00206)	(0.00073)	(0.00193)
L.$-VaR$			0.00232	-0.04197***
			(0.00703)	(0.00946)
L.log(Total Assets)			0.04403	0.01201
			(0.02650)	(0.00824)
L.ROA			-0.00136	-0.02516**
			(0.00517)	(0.01112)
L.Leverage			0.00001	0.00012***
			(0.00002)	(0.00004)
L.Loan Growth			-0.10807**	-0.15904
			(0.05004)	(0.09676)
Constant	0.09454	0.04708	-0.75429	0.14785
	(0.08038)	(0.05700)	(0.61322)	(0.17770)
Observations	4,284	4,284	4,084	4,084
R-squared	0.82454		0.82194	
Number of Banks	127	127	122	122
Methodology	FE	GMM	FE	GMM
Test for AR(1) (p-value)		0.000		0.000
Test for AR(2) (p-value)		0.726		0.384
Hansen Test (p-value)		1.000		1.000

Regression results for Equation 3.5. The first and third column show results from an OLS regression using time and bank fixed effects. The second and fourth columns show the results of a system GMM estimation with time dummies. The credit gap variable and the VaR are treated as potentially endogenous. The instruments used are the fifth and the sixth lag of the dependent variable and the second and third lag of the credit gap and VaR (differenced equation) and $\Delta y_{i,t-4}, \Delta creditgap_{i,t-1}, \Delta VaR_{i,t-1}$ (level equation). All bank balance sheet variables are treated as predetermined such that these instruments are used only in the level equation. We choose the minimum lag structure of the instruments in order to mitigate a problem of weak instruments. AR(1) and AR(2) are tests for first-order and second-order serial correlation in the first-differenced residuals with the null of no serial correlation. Standard errors are clustered at the country level throughout (in parentheses). ***, **, * indicate significance at the 1%, 5% and 10% levels.

3.D.2 Value at Risk

Table 3.12: Robustness Asset Risk - moving average of the credit gap over 12 quarters

	(1)	(2)	(3)	(4)
VARIABLES	$-VaR$	$-VaR$	$-VaR$	$-VaR$
L.$-VaR$	0.83390***	0.77578***	0.81399***	0.69675***
	(0.05309)	(0.08311)	(0.05577)	(0.10824)
L2.$-VaR$	-0.16144***	-0.19020***	-0.16126***	-0.17815***
	(0.05060)	(0.05063)	(0.05020)	(0.05259)
L3.$-VaR$	-0.03274	-0.10756***	-0.04057	-0.10326**
	(0.02538)	(0.03970)	(0.02538)	(0.04648)
L4.$-VaR$	0.13340***	0.24191***	0.13216***	0.18962***
	(0.02161)	(0.03544)	(0.02322)	(0.04958)
Credit Gap (1Y)	0.01019**	0.02183***	0.01207***	0.02909***
	(0.00376)	(0.00487)	(0.00404)	(0.00744)
L.log(Total Assets)			0.46930***	0.09405**
			(0.11870)	(0.04726)
L.ROA			-0.13982***	-0.29951**
			(0.04116)	(0.13348)
L.Leverage			-0.00019**	0.00103**
			(0.00008)	(0.00046)
L.Loan Growth			-0.48858	-0.30222
			(0.31626)	(0.56910)
Constant	0.13000	0.75194	-8.47438***	0.30951
	(0.63526)	(1.23415)	(2.73210)	(1.58864)
Observations	4,284	4,284	4,084	4,084
R-squared	0.87111		0.86978	
Number of Banks	127	127	122	122
Methodology	FE	GMM	FE	GMM
Test for AR(1) (p-value)		0.000		0.000
Test for AR(2) (p-value)		0.734		0.797
Hansen Test (p-value)		1.000		1.000

Regression results for Equation 3.5. The first and third column show results from an OLS regression using time and bank fixed effects. The second and fourth columns show the results of a system GMM estimation with time dummies. The credit gap variable is treated as potentially endogenous. The instruments used are the fifth and the sixth lag of the dependent variable and the second and third lag of the credit gap (differenced equation) and $\Delta y_{i,t-4}, \Delta creditgap_{i,t-1}$ (level equation). All bank balance sheet variables are treated as predetermined such that these instruments are used only in the level equation. We choose the minimum lag structure of the instruments in order to mitigate a problem of weak instruments. AR(1) and AR(2) are tests for first-order and second-order serial correlation in the first-differenced residuals with the null of no serial correlation. Standard errors are clustered at the country level throughout (in parentheses). ***, **, * indicate significance at the 1%, 5% and 10% levels.

3.E Cluster Standard Errors at Bank Level

3.E.1 Conditional Value at Risk

Table 3.13: Robustness Systemic Risk - cluster standard errors at bank level

VARIABLES	(1) $-\Delta CoVaR$	(2) $-\Delta CoVaR$	(3) $-\Delta CoVaR$	(4) $-\Delta CoVaR$
L.$-\Delta CoVaR$	0.86345***	0.88892***	0.85217***	1.00764***
	(0.01882)	(0.01923)	(0.02149)	(0.02029)
L2.$-\Delta CoVaR$	-0.18102***	-0.16133***	-0.18132***	-0.22699***
	(0.02434)	(0.02416)	(0.02530)	(0.02936)
L3.$-\Delta CoVaR$	-0.03390*	-0.10884***	-0.03496*	-0.09262***
	(0.01829)	(0.02022)	(0.01878)	(0.02733)
L4.$-\Delta CoVaR$	0.14548***	0.28922***	0.14265***	0.23550***
	(0.01269)	(0.02019)	(0.01316)	(0.02013)
Credit Gap	0.00145***	0.00406***	0.00163***	0.00528***
	(0.00039)	(0.00087)	(0.00041)	(0.00076)
L.$-VaR$			0.00228	-0.03970***
			(0.00310)	(0.00383)
L.log(Total Assets)			0.04477*	0.01392**
			(0.02559)	(0.00666)
L.ROA			-0.00159	-0.02333***
			(0.00411)	(0.00768)
L.Leverage			0.00001	0.00012***
			(0.00002)	(0.00002)
L.Loan Growth			-0.10763**	-0.14311
			(0.04444)	(0.09712)
Constant	0.09184***	0.04031**	-0.77133	0.06503
	(0.02584)	(0.01704)	(0.49279)	(0.13374)
Observations	4,284	4,284	4,084	4,084
R-squared	0.82453		0.82194	
Number of Banks	127	127	122	122
Methodology	FE	GMM	FE	GMM
Test for AR(1) (p-value)		0.000		0.000
Test for AR(2) (p-value)		0.517		0.207
Hansen Test (p-value)		1.000		1.000

Regression results for Equation 3.5. The first and third column show results from an OLS regression using time and bank fixed effects. The second and fourth columns show the results of a system GMM estimation with time dummies. The credit gap variable and the VaR are treated as potentially endogenous. The instruments used are the fifth and the sixth lag of the dependent variable and the second and third lag of the credit gap and VaR (differenced equation) and $\Delta y_{i,t-4}, \Delta creditgap_{i,t-1}, \Delta VaR_{i,t-1}$ (level equation). All bank balance sheet variables are treated as predetermined such that these instruments are used only in the level equation. We choose the minimum lag structure of the instruments in order to mitigate a problem of weak instruments. AR(1) and AR(2) are tests for first-order and second-order serial correlation in the first-differenced residuals with the null of no serial correlation. Standard errors are clustered at the bank level throughout (in parentheses). ***, **, * indicate significance at the 1%, 5% and 10% levels.

3.E.2 Value at Risk

Table 3.14: Robustness Asset Risk - cluster standard errors at bank level

VARIABLES	(1) $-VaR$	(2) $-VaR$	(3) $-VaR$	(4) $-VaR$
L.$-VaR$	0.83338***	0.76944***	0.81308***	0.70097***
	(0.02331)	(0.03601)	(0.02525)	(0.04015)
L2.$-VaR$	-0.16128***	-0.19436***	-0.16106***	-0.17509***
	(0.02504)	(0.03131)	(0.02488)	(0.03239)
L3.$-VaR$	-0.03292*	-0.10829***	-0.04086**	-0.11164***
	(0.01731)	(0.02978)	(0.01767)	(0.02794)
L4.$-VaR$	0.13511***	0.25644***	0.13427***	0.21476***
	(0.01271)	(0.02776)	(0.01242)	(0.03016)
Credit Gap	0.00996***	0.02433***	0.01191***	0.02778***
	(0.00167)	(0.00468)	(0.00164)	(0.00513)
L.log(Total Assets)			0.47645***	0.09657*
			(0.12486)	(0.04980)
L.ROA			-0.14124***	-0.28251***
			(0.03009)	(0.06299)
L.Leverage			-0.00019**	0.00097***
			(0.00009)	(0.00026)
L.Loan Growth			-0.48328**	-0.23120
			(0.24294)	(0.53703)
Constant	0.10899	1.78650***	-8.63336***	0.74082
	(0.20794)	(0.22463)	(2.40410)	(0.83484)
Observations	4,284	4,284	4,084	4,084
R-squared	0.87124		0.86999	
Number of Banks	127	127	122	122
Methodology	FE	GMM	FE	GMM
Test for AR(1) (p-value)		0.000		0.000
Test for AR(2) (p-value)		0.479		0.702
Hansen Test (p-value)		1.000		1.000

Regression results for Equation 3.5. The first and third column show results from an OLS regression using time and bank fixed effects. The second and fourth columns show the results of a system GMM estimation with time dummies. The credit gap variable is treated as potentially endogenous. The instruments used are the fifth and the sixth lag of the dependent variable and the second and third lag of the credit gap (differenced equation) and $\Delta y_{i,t-4}, \Delta creditgap_{i,t-1}$ (level equation). All bank balance sheet variables are treated as predetermined such that these instruments are used only in the level equation. We choose the minimum lag structure of the instruments in order to mitigate a problem of weak instruments. AR(1) and AR(2) are tests for first-order and second-order serial correlation in the first-differenced residuals with the null of no serial correlation. Standard errors are clustered at the bank level throughout (in parentheses). ***, **, * indicate significance at the 1%, 5% and 10% levels.

Chapter **4**

Why Banks Are Not Too Big To Fail Evidence from the CDS Market

This chapter is based on joint work with Isabel Schnabel.

This is a pre-copy-editing, author-produced PDF of an article accepted for publication in Economic Policy following peer review. The definitive publisher-authenticated version [Barth, A., and I. Schnabel (2013): “Why banks are not too big to fail - evidence from the CDS market,” *E*conomic Policy,, 28(74), 335-369] is available online at: http://economicpolicy.oxfordjournals.org/content/economicpolicy/28/74/335.full.pdf.

4.1 Introduction

The too-big-to-fail doctrine is a widely accepted hypothesis. It is argued that large banks benefit from implicit bail-out guarantees because no government is willing to hazard the consequences of a large bank's default on the financial system and on the economy as a whole. Such guarantees effectively constitute a government subsidy, which should be reflected in market prices. We argue in this chapter that bail-out probabilities depend on a bank's systemic importance rather than its size, and that the two concepts do not necessarily coincide. It is the systemic risk emanating from a bank, which justifies government intervention. Therefore, banks are not too big to fail (TBTF), but too systemic to fail (TSTF). Quite on the contrary, size may actually reduce bail-out expectations, as the events in Iceland in the fall of 2008 have shown. Being a small country, Iceland had a banking sector consisting mainly of three banks, which had vast balance sheets relative to Icelandic GDP. When these institutions got into distress, the Icelandic government was simply not able to bail them out. Consequently, the tremendous size made those banks too big to save (TBTS) rather than too big to fail.

While the TBTF problem has been discussed extensively in the literature (see, e.g. Boyd and Gertler (1994); Kaufman (2002); Stern and Feldman (2004)), the TBTS problem has received attention only recently. An early discussion of the TBTS problem is by Hellwig (1998) who argues that bank mergers in response to the too-big-to-fail problem may make some institutions “too big to be rescued.” Hüpkes (2005) stresses that the TBTS problem depends on a country’s size. Large complex financial institutions may be too large to be saved especially in “small economies such as Belgium, the Netherlands, Sweden and Switzerland” (Hüpkes (2005)). Rime (2005) empirically analyzes the effect of bank size on bank issuer ratings. As proxies of too-big-to-fail expectations, he includes absolute bank size and bank market shares. As proxy of the TBTS problem, he uses the ratio of total bank liabilities to GDP. The results confirm the existence of a TBTF effect, whereas there is no evidence of TBTS expectations in banks’ issuer ratings.

This chapter is most closely related to the work by Völz and Wedow (2011) and Demirgüç-Kunt and Huizinga (2013), who both study the effect of bank size on CDS spreads. In Völz and Wedow (2011), size is measured by the ratio of a bank’s market capitalization over the home country’s GDP. In order to allow for TBTS effects, they also include a quadratic term of this variable. They confirm that larger banks generally exhibit lower CDS spreads, supporting the presence of a TBTF problem. However, the relationship between bank size and CDS spreads is shown to revert at some point, suggesting that some banks have already reached a size that makes them too big to rescue (Völz and Wedow (2011)). In a similar vein, Demirgüç-Kunt and Huizinga (2013) find evidence of TBTF and TBTS in equity prices, but less so in CDS spreads. This finding is somewhat surprising as the theoretical effect on CDS spreads is more straightforward than that on equity prices. To identify TBTF, the authors consider the effect of a bank’s total assets on CDS spreads. In contrast, TBTS is measured by relative bank size, i.e. bank liabilities over GDP. Demirgüç-Kunt and Huizinga (2013) also consider interaction terms between relative bank size and a country’s debt over GDP ratio or its fiscal balance. Indeed, in some (though not all) regressions, the effect of relative bank size varies depending on the home country’s debt level and fiscal balance, supporting the idea of a TBTS problem.

We argue in this chapter that the notion of a bank being too big to fail is to unspecific because it mixes different effects of bank size, which may even go into opposite directions. Although the two papers described above claim to provide empirical evidence for banks being too big to fail and too big to save, their analyzes are in our view not able to clearly distinguish between these phenomena. Both TBTF and TBTS are measured on the basis of banks’ size, and the findings can therefore not easily be attributed to one of the two phenomena. Using non-linear regression functions or interaction terms does not adequately solve this problem. The too-big-to-save phenomenon cannot fully be captured by the convexity of the regression function because this does not take into account the fiscal situation of the home country. The too-big-to-fail problem - or too-systemic-to-fail problem, as we prefer to call it - is not adequately captured by a bank's total assets because absolute bank size is only a crude proxy of systemic relevance. Whether a bank is too systemic to fail is not only determined by its size, but also by its interconnectedness and its correlation with the remaining banking sector, as has also been argued recently by Zhou (2010). It further depends on whether a bank's services can easily be substituted by other agents in the financial system, an aspect that is largely ignored in the literature. Absolute bank size may be one factor that makes a bank less substitutable; another is whether a financial system is bank- or market-based. Substitutability will generally be lower in bank-based financial systems.

Moreover, the economic context matters for a bank's systemic importance. For example, if a small bank is hit by a shock in non-crisis times, it would hardly be regarded as being systemic. But in the middle of a financial crisis, even a small bank may be rescued due to the fear of contagion effects. The rescue of the German bank IKB is a case in point. Given that total assets change only slowly over time and that changes are only vaguely related to changes in systemic significance, bank size is not able to capture the importance of the economic circumstances. Therefore, one has to consider broader measures of systemic relevance than just size.

We propose to identify the TSTF problem by employing a broad measure of systemic risk, namely the contribution of an individual bank to the system's risk, measured by $\Delta CoVaR$ as proposed by Adrian and Brunnermeier (2011). Once we control for the TSTF phenomenon, we can identify the effect of being too big to save by a bank's size relative to GDP. We also include absolute bank size. Given an appropriate measure of systemic risk, this should capture other factors, such as the substitutability of banks or diversification benefits. We also control for the importance of banks in a financial system.

In addition to measuring the overall importance of TSTF and TBTS, we analyze how the importance changed over the financial crisis. For that purpose, we divide our sample into three sub-periods. The first period starts in 2005 and ends in July 2007, just before the beginning of the financial crisis. The second period comprises the first crisis phase until August 2008. Finally, the third period starts with the failure of the US bank Lehman Brothers in September 2008. Before the financial crisis, bail-out expectations are not expected to play a large role. CDS spreads were very low even for non-systemic banks. This is likely to change with the onset of the crisis when the TSTF problem is expected to become much more pronounced. In contrast, the Lehman default and the emergence of sovereign debt problems in Iceland showed that even systemic banks may not be bailed out under all circumstances.

Our results suggest that markets indeed reflect banks' contribution to systemic risk. A higher contribution to systemic risk (corresponding to a lower $\Delta CoVaR$) translates into lower CDS spreads, supporting the existence of TSTF. Bank size (relative to GDP) does not matter when the bank's home country has low debt levels. However, the effect of bank size increases in the debt ratio of the home country and becomes positive at moderate debt levels. These results are robust across many different specifications. Splitting the sample in sub-periods is also instructive. We find that TSTF was not priced in the CDS market before the financial crisis erupted in 2007. However, the importance of TSTF rises sharply after August 2007, before it weakens again after the Lehman collapse. In contrast, the TBTS problem is robust across the three subperiods.

The chapter is organized as follows. In Section 4.2, we introduce the concepts of banks being too systemic to fail or too big to be saved, and discuss why bank size is only a crude proxy of systemic risk. Section 4.3 introduces the empirical model, states the main hypotheses, provides data sources and describes the major variables used in the empirical analysis. The empirical results from our baseline regressions are shown in Section 4.4. In Section 4.5, we show empirical results for the three sub-periods of our sample - pre-crisis, beginning of crisis, and post-Lehman. Section 4.6 concludes.

4.2 Too Systemic To Fail versus Too Big To Fail

4.2.1 Systemic risk and bank size

Bail-out expectations depend on the systemic risk emanating from a financial institution. The larger are the repercussions of an institution's failure on the financial system and the real economy, the more it should be considered systemically important and the more likely it is to be bailed out. In order to provide a proper definition of the concept of systemic importance, we have to analyze the driving forces of different channels of contagion.

In the literature, there are four channels of contagion from the distress of one institution to the rest of the financial system. First, there is an information contagion channel, as introduced by Chen (1999) and Acharya and Yorulmazer (2008). They show that contagion may arise due to new information revealed to depositors after a bank failure. Observing difficulties at one bank, depositors of other banks fear that their bank subsequently experiences financial troubles as well and withdraw their deposits, which can result in a bank run. The amplitude of this contagion channel depends on the similarity of financial institutions. Second, the failure of a financial institution may infect other institutions with significant direct credit exposures at this bank. This form of contagion via the interbank market, as shown by Allen and Gale (2000), arises when a default of one bank results in significant write-offs of claims at the failed bank. This can be sufficient to generate trouble in the whole financial system. The dominant determinant of the magnitude of repercussion effects through this channel is the interconnectedness of banks. The third contagion channel works via macro-economic feedbacks. Brunnermeier and Pedersen (2009) model this form of contagion in terms of liquidity spirals. They show that, if banks hold similar assets and one bank has to sell assets at a fire-sale price due to short liquidity, these fire sales of the illiquid bank depress asset prices, which also affects other banks. Such domino effects through asset prices can happen even in the absence of bank defaults infecting other financial institutions. A decline in prices is already sufficient. The severity of this channel is mostly driven by the correlation among financial institutions, but also by their size. Furthermore, the impact of fire sales is determined to a large extent by the economic context. In times of financial crises, many banks suffer simultaneously from short liquidity and must sell assets at fire sale prices. Thus, in distress periods, the behaviour of many small banks with correlated portfolios has the same impact on prices as the action of one single huge bank. This is essentially a "too-many-to-fail" problem (Acharya and Yorulmazer (2007)). Fourth, contagion may arise from self-fulfilling expectations. The argument of this channel works similar to the bad equilibrium of the seminal work of Diamond and Dybvig (1983). The failure of one financial institution coordinates expectations of all investors and depositors, such that investors and depositors start a run. Since the crucial element of this channel is expectations, the probability of contagion effects are mostly driven by two factors: size and context. Investors are more likely to coordinate on the failure of a large bank. However, if the financial sector is in a critical condition, the collapse of a small bank can be sufficient to give rise to bad expectations of all investors and depositors. In calm periods, the collapse of the same bank would not bother investors or depositors at all.

The channels of contagion described above all refer to repercussions within the financial sector. To fully capture the systemic importance of an institution, one also has to consider the repercussions of a bank's failure on the real economy. These repercussions will depend strongly on whether an institution's service can easily be substituted by other agents in the economy. Hence, the substitutability of a financial institution is another crucial determinant of its systemic importance and hence of its bail-out probability. Size is only a crude proxy, since substitutability also depends on the characteristics of the financial system (e.g., the question whether a financial system is bank- or market-based).

Thus, we can conclude that it is not only the size of a bank which drives its systemic importance. There are many other factors playing a vital role, especially interconnectedness, correlation, substitutability, and the economic context. Hence, the preceding discussion suggests that measuring the systemic importance of a bank by its size is too narrow. Nevertheless, most empirical work so far has focused on the too-big-to-fail problem. We argue that one should take a broader perspective to capture all facets of systemic risk.

4.2.2 Measuring systemic risk within the financial sector by conditional value at risk

In this chapter, we measure systemic importance within the financial system using $\Delta CoVaR_t^i$, a measure introduced by Adrian and Brunnermeier (2011). This measure tries to capture an individual institution's contribution to overall systemic risk within a financial system. Due to the comprehensive nature of this variable, it captures not only a bank's size, but also other factors, such as its correlation with other banks, as well as the economic context.

A bank's CoVaR relative to the system is defined as the conditional value at risk, i.e. the q%-VaR of the whole financial sector conditional on the fact that an institution i is at its VaR level:

$$CoVaR_q^{system|X^i=VaR_q^i} := VaR_q^{system}|VaR_q^i \tag{4.1}$$

It thus gives the maximum dollar loss of the financial system at probability q conditional on institution i being in distress. Throughout the chapter, we are using a stress level of 1%.

Following the procedure proposed by Adrian and Brunnermeier (2011), we estimate $CoVaR_t^i$ by using quantile regression, as is explained in more detail in Appendix A1. We allow for the time variation of $CoVaR_t^i$ by including a set of lagged state variables in the estimation. Our measure of systemic risk, $\Delta CoVaR_t^i$, is defined as the difference between $CoVaR_t^i$ conditioned on distress of bank i versus normal times, where normal times are characterized by the median. Hence, it is calculated as follows, using again the 1% stress level:

$$\Delta CoVaR_t^i(1\%) = CoVaR_t^i(1\%) - CoVaR_t^i(50\%). \tag{4.2}$$

From the quantile regressions, we obtain a panel of daily $\Delta CoVaR_t^i$, measuring the risk contribution of each individual institution to the system. It should capture all the determinants of the financial contagion channels described in Section 4.2, i.e. the systemic importance deriving from correlation, size, interconnectedness, and from the economic context. Since $\Delta CoVaR_t^i$ is typically negative, with a more negative value indicating a greater contribution to systemic risk, we use $-\Delta CoVaR_t^i$ throughout the chapter, implying that an increase in this variable is to be interpreted as an increase in the contribution to systemic risk.

In our main specification, the financial system is defined as all banks located in the same continent. This implicitly assumes that this is the level at which bail-out decisions are taken. Alternatively, we consider the United Kingdom and Switzerland as separate financial systems. Note that a finer definition of financial systems leads to higher values of $-\Delta CoVaR$ because an individual bank's effect on the system return increases. When the definition becomes too fine such that very few banks are contained in each system, the measure becomes less useful. Our choice reflects the trade-off between capturing the right level of bail-out decisions and having a sufficient number of banks in the considered financial system.

Our data illustrate the difference between bank size and systemic risk.[1] We find a low correlation of 0.052 between the ratio of bank liabilities to GDP (which is used in the literature to measure the TBTF and TBTS phenomena) and $-\Delta CoVaR$ (as our measure of TSTF), and a moderate correlation of 0.248 between absolute bank size and $-\Delta CoVaR$.

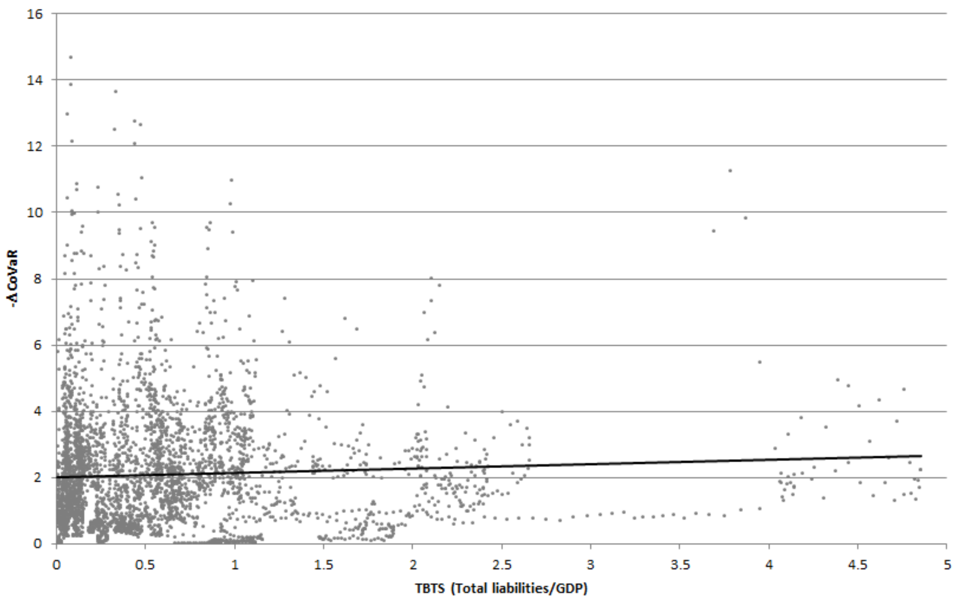


Figure 4.1: Scatter plot of $-\Delta CoVaR$ and the ratio of bank liabilities to GDP (TBTS). Sources: Own calculations, Bankscope, WDI.

The scatter plots in Figures 4.1 and 4.2 confirm our doubts about the suitability of absolute and relative bank size as proxies of systemic relevance. A large part of the

[1] See Section 4.3.3 for a description of data sources.

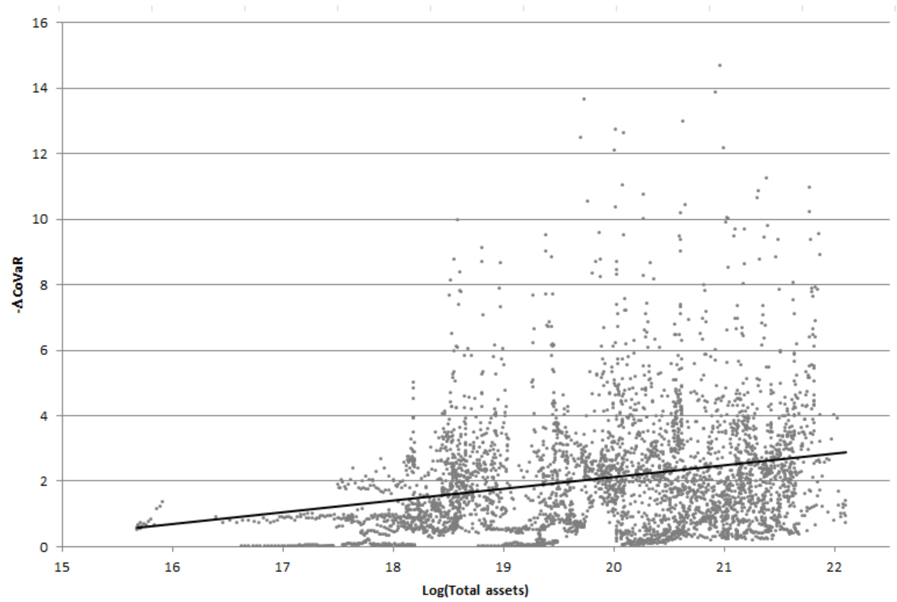


Figure 4.2: Scatter plot of $-\Delta CoVaR$ and the log of total bank assets. Sources: Own calculations, Bankscope.

dispersion of $-\Delta CoVaR$ cannot be explained by the two size measures. In a regression of $-\Delta CoVaR$ on the TBTS and absolute bank size, only 7.6% of the variation of systemic risk are explained. The most prominent examples of banks that are small relative to home country's GDP but that contribute to a large extent to systemic risk are US investment banks. For example, Goldman Sachs had a ratio of liabilities to GDP of only 6.1% in November 2008 (17%-quantile of our sample), log total assets of 20.6 (67%-quantile), but a contribution to systemic risk, $-\Delta CoVaR$, of 10.5 (99%-quantile). In Europe, the UK bank Lloyds TSB had at the same time a $-\Delta CoVaR$ of 10.0 (99%-quantile), with a relative size ratio of 22.9% of GDP (41%-quantile) and log total assets of 20.3 (56%-quantile). In contrast, there are also banks with huge size, but only a limited contribution to overall systemic risk. For example, the Belgium bank Dexia had in January 2007 a huge relative size of 180.6% of its home country's GDP (93%-quantile) and log total assets of 20.4 (60%-quantile), but a limited systemic relevance indicated by a $-\Delta CoVaR$ of 0.2 (7%-quantile). Similarly, the Icelandic bank Kaupthing had in January 2006 an immense relative size of 228.0% of the Icelandic GDP (97%-quantile), but a $-\Delta CoVaR$ of only 0.6 (18%-quantile) and small absolute size of 17.5 (3%-quantile).

Moreover, a systemic risk measure should reflect the economic context, i.e. it should be higher in times of crisis. As is shown in Table 4.1, $-\Delta CoVaR$ suggests a sharp increase in systemic risk during the financial crisis by more than one standard deviation of its pre-crisis level and a further rise after the default of Lehman Brothers. Both the ratio of bank liabilities to GDP and the log of total assets, however, hardly mirror the crisis: the means of both measures increase only slightly in the crisis period and even drop in the post-Lehman period.

Table 4.1: Evolution of $-\Delta CoVaR$ and absolute and relative bank size

Variable	Mean	Std. Dev.	Min.	Max.	N
		Pre-crisis period			
$-\Delta CoVaR$	1.169	0.776	0.020	4.745	1482
TBTS	0.590	0.829	0.004	4.852	1482
Log(Total assets)	19.75	1.21	16.46	21.76	1482
		Crisis period			
$-\Delta CoVaR$	2.173	1.354	0.02	7.181	807
TBTS	0.639	0.835	0.009	4.792	807
Log(Total assets)	19.95	1.24	17.37	22.10	807
		Post-Lehman period			
$-\Delta CoVaR$	2.802	2.211	0.029	14.69	1787
TBTS	0.528	0.512	0.006	4.033	1787
Log(Total assets)	19.93	1.26	15.68	22.06	1787

Notes: Descriptive statistics for $-\Delta CoVaR$, TBTS, and Log(Total assets). The pre-crisis period denotes the time until July 2007. The crisis period is the period from August 2007 to August 2008. The post-Lehman period starts in September 2008.

Figure 4.3 displays the time variation of $-\Delta CoVaR$ over the sample period. We see a sharp increase in the middle of 2007, and especially towards the end of 2008. Another spike shows up at the onset of the European debt crisis. Comparable movements cannot be seen in measures of banks' absolute or relative size.

4.2.3 Too big to save

The recent crisis has shown that banks cannot just be too big to fail, but also too big to save (TBTS). In particular, if the size of a financial institution exceeds a country's ability of a bail-out, the bank simply cannot be rescued by the safety net. Therefore, we do not expect that banks will necessarily benefit more from a country's safety net if they are bigger, especially when controlling for systemic risk. While the too-big-to-fail doctrine argues that banks' size increases the bail-out probability, we argue that it is the systemic importance of banks that drives bail-out expectations. Hence, a bank's size relative to the economy should decrease the bailout probability conditional on systemic risk. In this sense, TBTS can be seen as the antagonist of the too-systemic-to-fail problem.

Figure 4.3: Evolution of $-\Delta CoVaR$ over the sample period. Sources: Own calculations.

The most prominent recent example of banks being too big to save was the case of Iceland, which experienced considerable economic trouble due to its banking sector. The financial turmoil resulted in strong losses of its internationally active banks, which had vast balance sheets relative to the size of the economy.[2] Consequently, the Icelandic Financial Supervisory Authority took control of these banks within one week in October 2008. It is instructive to compare the CDS spreads, as indicators of the market's default expectation, of the Icelandic bank Kaupthing and the German bank IKB, two institutions of similar size that both faced serious troubles during the recent financial crisis. Figure 4.4 suggests that markets perceived a sharp disparity in the bail-out probabilities of the two banks.

4.3 Empirical Analysis

4.3.1 Hypotheses

Our empirical analysis attempts to explain the evolution of bank CDS spreads. A credit default swap (CDS) is an insurance contract against default or other types of credit events. More precisely, the protection buyer pays a default swap premium for receiving the guarantee that the protection seller covers the incurred losses if a default is triggered.

[2]Total assets of the three largest banks relative to GDP skyrocketed from less than 200% in 2003 to almost 1000% in 2008, cf. The Central Bank of Iceland (2009).

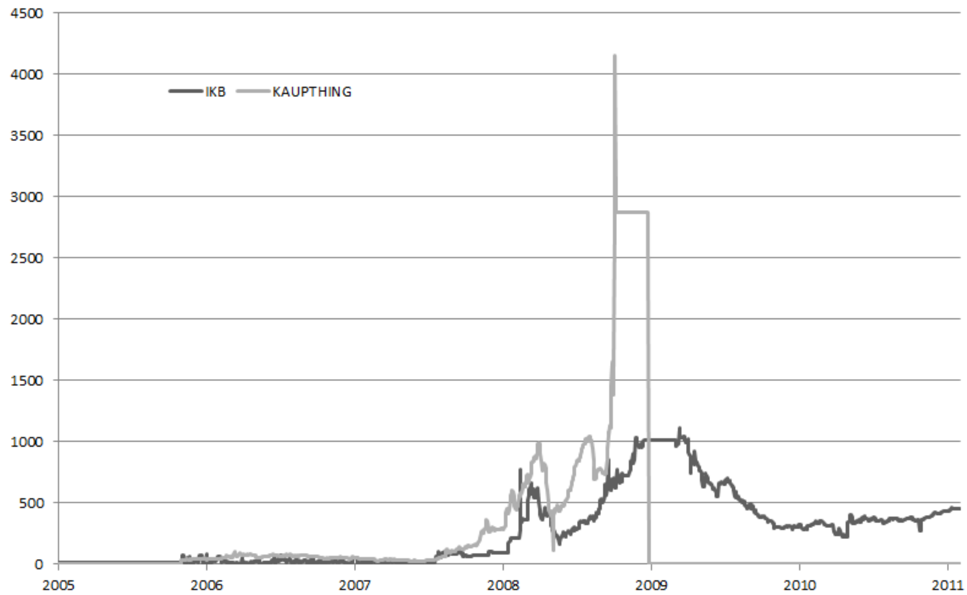


Figure 4.4: CDS spreads of the Icelandic bank Kaupthing and the German bank IKB. At the end of 2008, the CDS of Kauphings jumps close to zero and hardly moves in the following month until it became untraded (July 2010). Sources: Datastream.

Therefore, the price of a bank CDS is a function of the expected losses on bank liabilities, with expected losses depending on the (expected) probability of default (PD) and loss given default (LGD):

$$\textit{Expected losses} \;=\; PD \cdot LGD$$

The market expectation of banks' PD is a function of the bank-specific fundamental PD and the probability of a government bail-out in case of distress:

$$PD \;= (1 - \textit{bail-out probability} \mid \textit{fundamental default}\;) \cdot \textit{fundamental PD}. \tag{4.3}$$

Hence, CDS spreads are a function of the (expected) fundamental PD, the bail-out probability, and the loss given default.

We now formulate three hypotheses that will be tested in the empirical analysis. The first hypothesis refers to the too-systemic-to-fail problem. Since the consequences of the failure of a systemic institution for the rest of the financial system can be enormous, a bank is the more likely to be rescued by the government, the higher is its systemic risk. We therefore expect that systemic banks have a lower market expectation of default, which should show up in lower CDS spreads, as postulated by Hypothesis 3.

Hypothesis 3 (Too systemic to fail)**.** *Ceteris paribus, CDS spreads are smaller for banks with a higher contribution to systemic risk.*

For a given level of systemic importance, there are no incentives for a government to bail out a bank just because of its size. To the contrary, the country may not be able to bail out a financial institution if it has grown too large relative to its home country's GDP. The ability of a country to bail out banks depends on the country's fiscal situation (cf. Buiter and Sibert (2008); Demirgüç-Kunt and Huizinga (2013)). Even if financial institutions are large relative to GDP, a government may still be able to bail them out if the country has a high debt capacity. In this situation, CDS spreads may not respond much to banks' size. In contrast, a bail-out may not be feasible for countries with already high debt levels. In this case, the effect of (relative) bank size on CDS spreads is expected to be much stronger. By controlling for systemic risk, we can isolate a country's willingness to conduct a bail-out (Hypothesis 3) from its ability to do so. This leads us to Hypothesis 3.

Hypothesis 3 (Too big to save)**.** *Ceteris paribus, the effect of a bank's relative size on CDS spreads increases in a country's debt level.*

Finally, banks are more likely to be bailed out if their services are hardly substitutable by other parts of the financial system. In such a situation, bank distress would have dire consequences for the real economy. For example, in a bank-based system, banks play a more crucial role than in a market-based system. Therefore, if the real economy in a country is strongly reliant upon the banking sector (showing up in a high ratio of domestic credit relative to GDP), a government may be more likely to bail out financial institutions, implying lower CDS spreads. Substitutability may also be related to banks' absolute size because large banks' services cannot as easily be substituted as those provided by smaller banks. Such an effect would not be captured by our TSTF measure. This yields the prediction of Hypothesis 3.

Hypothesis 3 (Substitutability)**.** *Ceteris paribus, CDS spreads are larger for banks that are more easily substitutable.*

Summing up, our main hypotheses are that (i) a bank's systemic importance lowers CDS spreads, (ii) the effect of bank size relative to GDP is stronger for banks in highly indebted countries, and (iii) substitutability raises CDS spreads.

4.3.2 Empirical model

In our empirical analysis, we model bank CDS spreads as a function of bank-specific and country-specific characteristics. Since CDS spreads cannot be regarded as stationary (especially in times of financial turmoil), we estimate our model in first differences. [3] We model the first difference of the CDS spread of bank i in country j at time t as follows:[4]

$$\begin{aligned}\Delta CDS_{i,j,t} =& \alpha + \beta \cdot \Delta TSTF_{i,j,t-1} + \gamma \cdot \Delta TBTS_{i,j,t-1} + \delta \cdot Delta(TBTS_{i,j,t-1} \cdot debtratio_{j,t-1}) \\ &+ \lambda \cdot \Delta log(size)_{i,j,t-1} + \kappa \cdot \Delta Domcred_{j,t-1} + \theta \cdot X_{i,j,t-1} + \mu_i + \gamma_t + u_{i,j,t}.\end{aligned} \tag{4.4}$$

TSTF measures a bank's contribution to systemic risk, $-\Delta CoVaR$ (see Section 4.2.2).[5] According to Hypothesis 3 ("too systemic to fail"), β should be negative. TBTS, defined as bank liabilities over GDP, captures the ability of governments to bail out banks.[6] We also include an interaction term of TBTS and the ratio of government debt to GDP, as the effect of a bank's (relative) size may depend on the debt level of its home country. This allows us to test Hypothesis 3 ("too big to save"), which predicts that the coefficient of the interaction term, δ, is positive.

The ratio of domestic credit over GDP is used as measure of a bank's substitutability in a given country. According to Hypothesis 3 ("substitutability"), κ is expected to be negative. Substitutability may also be related to absolute bank size (in logs), which would lead to a negative sign of λ. At a given level of systemic risk, absolute bank size captures the effect of a bank's size on the real economy, as financial contagion effects are already comprised by $-\Delta CoVaR$. However, absolute bank size may also capture determinants of the fundamental probability of default, such as the degree of diversification. $X_{i,j,t-1}$ are further variables determining the bail-out probability and the fundamental probability of default, both macroeconomic and bank-specific variables. The control variables are explained in detail below. All explanatory variables are lagged by one period to mitigate endogeneity problems. In order to take the unobserved heterogeneity of banks and over time into account, we include bank-specific fixed effects μ_i, as well as time fixed effects γ_t. Standard errors are clustered at the bank level to account for the autocorrelation of banks.

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[3] The non-stationarity of CDS spreads was confirmed in a panel unit root test. A Dickey Fuller test of CDS spreads in first differences, however, yields a p-value of 0.0041. Hence, the first differences are stationary. We choose 12 lags for these test following Schwert (1989). In a robustness check, we also present the regression results in levels.

[4] Note that the interpretation of the slope coefficients in the differenced model is analogous to that in a model specified in levels; therefore, we discuss the coefficients in terms of levels.

[5] $\Delta CoVaR$ enters with a negative sign to facilitate interpretation.

[6] In a robustness check, we use total bank assets instead of liabilities to construct the TBTS measure.

4.3.3 Data sources

We collect daily CDS data from Thomson Reuters Datastream. We focus on senior CDS with a maturity of five years, since it has been shown that trading liquidity is highest at this maturity (see European Central Bank (2008)). Our second main data source is Bureau van Dijk's Bankscope, which contains balance sheet information for a large number of banks from a broad set of countries. We use banks' consolidated statements for two reasons. On the one hand, CDS spreads refer to the entire financial institution, not only to the parent company. On the other hand, the events in Iceland have shown that the home country of the parent company might also be responsible for its branches abroad.[7] Moreover, we use national accounts data from the World Bank's World Development Indicators database (WDI). Since most of our exogenous variables are only available at yearly frequency, we use the monthly average of all variables with daily frequency and employ cubic spline interpolation for variables that are available only at yearly frequency.

Our analysis is based on the top 100 largest banks in the world, measured by total assets at the end of 2008, for which data was available. We expand the dataset by several banks, which already failed in 2008 over the course of the financial crisis. However, we do not restrict our sample regarding bank specialization. We start our sample in 2005 since before that time, trading activity in the CDS market was limited to only some banks and pricing information is incomplete, and we collect the data until the end of 2011.[8] Our final dataset includes 73 banks from 21 countries and spans seven years.

In the following, we will describe the included right-hand-side variables and present descriptive statistics of the data used in the analysis.[9]

The systemic relevance of a bank is measured by $-\Delta CoVaR$. In order to facilitate interpretation, we multiplied $\Delta CoVaR$ by -1 such that higher values of the variable indicate higher contributions to systemic risk.

We follow Buiter and Sibert (2008) in defining the determinants of the too-big-to-save problem (what they call the "vulnerable quartet"). According to these authors, TBTS is particularly considerable in "(i) small countries with (ii) a large, internationally exposed banking sector, (iii) its own currency, and (iv) limited fiscal spare capacity relative to the possible size of the banking sector solvency gap." In line with this characterization, we measure bank size relative to a country's GDP. To control for the limited fiscal spare

[7] A letter of Iceland's Minister of Business Affairs to the British Treasury from 2008 says that "if needed the Icelandic Government will support the Depositors' and Investors' Guarantee Fund in raising the necessary funds, so that the Fund would be able to meet the minimum compensation limits in the event of a failure of Landsbanki and its UK branch."

[8] Note that data coverage is relatively low in 2011 due to missing data.

[9] All details on the preparation of the dataset are listed in Table 4.6 in the Appendix.

capacity, we include the amount of government debt relative to GDP and government's foreign exchange reserves including gold relative to GDP from the World Bank's World Development Indicators (WDI). Both variables are essential for the question whether a country has enough resources or whether it can raise enough money for bailing out its banking sector. The higher the ratio of government debt to GDP, the more likely a bank is to be TBTS and the lower is the probability of a bank bail-out. Higher reserves indicate a higher ability of a sovereign to bail out its banks and thus make a bank less likely to be TBTS.

Finally, the substitutability of banks is measured by the amount of domestic credit provided by the banking sector in relation to the GDP from the World Bank's World Development Indicators (WDI) database. We also include a bank's absolute size, which is related to substitutability at the bank level, but cannot be fully disentangled from factors influencing the fundamental probability of default (e.g., diversification benefits).

We control for bank-specific characteristics affecting a bank's fundamental probability of default using two alternative approaches. First, we include the value at risk (-VaR) at the 1% level, the most common measure of risk used by financial institutions.[10] Second, we control for bank risk using the distance to default measured by the z-score. The z-score is defined as the sum of returns on assets and capital asset ratio (equity over total assets) divided by the standard deviation of the return on assets. It can be shown that this is just the inverse of the probability of insolvency and that it equals the number of standard deviations a bank's return on assets has to decline below its expected value until the bank is insolvent (see Beck, Hesse, Kick, and von Westernhagen (2009)). Following Lepetit, Nys, Rous, and Tarazi (2008), we use a market-based z-score, i.e. $z - score = (\overline{R}+1)/\sigma$, where $\overline{R}$ and σ are the mean and the standard deviation of yearly stock returns over the period [t-261, t]. A higher z-score is equivalent to a financially more stable bank. Furthermore, we consider different balance sheet ratios of risk in banking. First, we control for banks' leverage ratio (total assets over equity). Second, we include a bank's return on average assets to capture bank performance and profitability. At the country level, we use the growth rate of GDP in order to control for business cycle effects.

4.3.4 Descriptive statistics

We present descriptive statistics of bank characteristics in Table 4.2 and of country characteristics in Table 4.3.

[10] Just as -CoVaR, we multiply this variable by -1, such that a higher VaR indicates higher individual risk.

Table 4.2: Descriptive statistics of bank characteristics

Variable	Mean	Std. Dev.	Min.	Max.	N
CDS	108.9	166.4	3.3	4762	4076
CDS (winsorized)*	98.2	100.1	7.5	403.1	4076
$-\Delta CoVaR$	2.084	1.805	0.020	14.69	4076
$-\Delta CoVaR$ (winsorized)*	1.938	1.365	0.116	4.862	4076
TBTS (Total liabilities/GDP)	0.572	0.710	0.004	4.852	4076
TBTS assets (Total assets/GDP)	0.595	0.732	0.005	4.965	4076
Log(Total assets)	19.87	1.24	15.68	22.10	4076
-VaR	6.937	4.885	0.975	45.98	4076
-VaR (winsorized)*	6.537	3.448	2.091	14.79	4076
Z-score	9.087	9.742	0.475	113.1	4045
Z-score (winsorized)*	8.242	6.271	1.562	21.74	4045
Leverage	23.53	15.71	4.91	149.5	4076
ROAA	0.138	5.172	-97.44	3.069	4020

Notes: All variables labeled with * are winsorized at 5/95% before calculating monthly averages.

The average CDS spread is 108.9 basis points, the maximum value being more than 4700 basis points, realized by the Irish bank Anglo Irish Bank in January 2011. Furthermore, the mean of $-\Delta CoVaR$ is 2.08, which is slightly larger than in Adrian and Brunnermeier (2011) because our sample contains more stressful events than the sample in their paper. In order to deal with the extreme outliers of some banks in this data with daily frequency, we use a 5% winsorization before calculating monthly averages. This has the advantage of maintaining the information that some observations are extreme without allowing for an unduly strong impact of individual observations. The average ratio of liabilities to home country's GDP is 57.2%, while the largest institution in relative terms exceeds its home country's GDP by more than 380%, namely the Swiss bank UBS in 2007. The bank-specific risk of an individual institution, -VaR, has a sample mean of 6.94, with the Irish Bank of Ireland showing the highest level of individual risk in November 2008. The sample mean of the z-score is 9.09 with the largest number of 113.1 achieved by Bear Stearns in September 2006, a period when this bank was financially highly sound. In order to deal with such outliers, we also winsorize these variables at the 5% level. The lowest return on average assets of -97.44% comes from the Icelandic bank Glitnir in the aftermath of its failure. Moreover, the huge leverage ratio of 149.5 refers to the Belgian bank Dexia in 2010.

Table 4.3 shows descriptive statistics at the country level. The average ratio of domestic credit provided by the banking sector in relation to GDP is 173.4%, with the maximum value of 331.8% in Japan in 2010 and the minimum value of 57.6% in India in 2005.

Table 4.3: Descriptive statistics of country characteristics

Variable	Mean	Std. Dev.	Min.	Max.	N
Domestic credit / GDP	173.4	61.59	57.58	331.8	4044
Debtratio	62.18	31.03	18.03	175.0	4076
Reserves / GDP	0.098	0.189	0.003	1.094	4076
GDP growth	1.647	3.352	-7.240	14.76	4076

Moreover, we find in our dataset an average debt ratio of 62.2%, with Japan being the most indebted country in 2010 with a proportion of central government debt to GDP of 174.98%. Australia has the minimum debt ratio of 18.0% in 2008. The average growth rate amounts 1.65% with Singapore showing the highest growth rate in 2010.

4.4 Estimation Results in Baseline Specification

Table 4.4 presents the regression results from our baseline specification. The regression results show that a higher systemic importance, as measured by an increase in $-\Delta CoVaR$, significantly decreases CDS spreads in all specifications. This result strongly supports Hypothesis 3: The more a financial institution contributes to systemic risk, the more likely is a bail-out in order to prevent negative repercussion effects on the rest of the financial system, and the lower are the bank's CDS spreads.

We also find evidence that the effect of (relative) bank size depends on the home country's debt capacity. Bank size has no significant effect on bank CDS spreads in countries with a zero debt level (see the coefficient of TBTS). However, the effect increases in a country's debt ratio, consistent with the idea that countries with higher debt ratios are less able to bail out financial institutions. The overall effect of relative bank size becomes positive already at moderate debt ratios (between 13.8% in specification (2) up to 22.6% in specification (1)). Hence, a bail-out becomes less likely for large banks even at moderate sovereign debt levels, and the effect strengthens when the debt ratio increases, confirming Hypothesis 3. The significant coefficient of the debt ratio in specification (1) indicates that the government debt ratio positively affects the CDS spread for mean-sized banks.[11] However, this result is not robust across specifications.

Another interesting result concerns substitutability. Even though absolute bank size (the log of total assets) does not significantly affect CDS spreads, domestic credit over GDP has a significantly negative effect. Hence, in countries with a higher ratio of domestic

[11] In order to facilitate the interpretation of the debt coefficient, we demeaned the variable TBTS in our regressions. This does not affect any other coefficient (apart from the constant).

Table 4.4: Baseline regression in first differences with bank fixed effects and time fixed effects

VARIABLES	(1) CDS	(2) CDS	(3) CDS	(4) CDS	(5) CDS
$-\Delta CoVaR$	-2.881*	-2.899**	-3.016**	-4.924***	-4.940***
	(0.0514)	(0.0496)	(0.0460)	(0.0069)	(0.0068)
TBTS	-46.50	-31.23	-36.35	-34.17	-34.34
	(0.135)	(0.338)	(0.258)	(0.290)	(0.288)
TBTS * Debtratio	2.057**	2.268***	2.038**	1.951**	1.959**
	(0.0167)	(0.0086)	(0.0141)	(0.0187)	(0.0184)
Debtratio	1.875*	1.671	0.693	0.783	0.762
	(0.0907)	(0.132)	(0.587)	(0.539)	(0.550)
Log(Total assets)		-38.48	-33.33	-33.13	-33.62
		(0.145)	(0.152)	(0.157)	(0.150)
Domestic credit / GDP			-1.442*	-1.416*	-1.440*
			(0.0634)	(0.0671)	(0.0642)
GDP growth			-7.764***	-7.724***	-7.793***
			(0.0004)	(0.0004)	(0.0004)
Reserves / GDP			-4.409	-9.164	-8.331
			(0.979)	(0.956)	(0.960)
Leverage			0.0707	0.0605	0.0598
			(0.731)	(0.771)	(0.774)
ROAA			-0.715	-0.709	-0.706
			(0.171)	(0.174)	(0.178)
Z-score			-0.260		-0.258
			(0.286)		(0.290)
-VaR				1.242*	1.241*
				(0.0986)	(0.0990)
Constant	-1.789**	-1.476**	-1.390*	-1.637*	-1.771**
	(0.0178)	(0.0445)	(0.0731)	(0.0573)	(0.0454)
Observations	4,076	4,076	3,950	3,983	3,950
R-squared	0.436	0.437	0.440	0.441	0.441
Number of banks	73	73	72	72	72
Bank FE	YES	YES	YES	YES	YES
Time FE	YES	YES	YES	YES	YES
CoVaR	Continental	Continental	Continental	Continental	Continental

Notes: OLS regressions in first differences for Equation (4.4) with bank fixed effects and time fixed effects. Standard errors are clustered at the bank level throughout. p-value are given in parentheses. ***, **, * indicate significance at the 1%, 5%, and 10% levels. TBTS is demeaned before taking first differences. Sample sizes of different specifications differ due to data availability.

credit over GDP, bank CDS spreads tend to be lower. This is consistent with Hypothesis 3 that bail-out probabilities are smaller for banks than can more easily be substituted.

The remaining coefficients at the country level are in line with our expectations. We find that GDP growth has a significantly negative effect on banks' CDS spreads. Reserves (foreign exchange plus gold) have the expected negative sign, but are insignificant. At the bank level, we find no effect of leverage, the return on average assets (ROAA), or the z-score although all variables have the expected signs. In contrast, the bank's value at risk is significant and shows the expected sign. Hence, higher bank risk leads to higher CDS spreads, as expected.

We checked the robustness of our results in various ways. The results are shown in Table 4.8 in the Appendix as well as in the tables in Appendix 4.D. All robustness checks are based on the model in column (5) of Table 4.4, which includes the full set of control variables. We first re-estimate the model without including bank fixed effects (see column (1) of Table 4.8). All major results remain unchanged. Only the ROAA now becomes significant with the expected sign, whereas domestic credit is no longer significant. We then run the regression in levels instead of first differences, including bank fixed effects and a lagged dependent variable to account for the strong autocorrelation in CDS spreads (column (2) in the same table). As expected, the lagged dependent variable shows a coefficient that is close to 1 (0.905). The results are again very similar to our baseline regression, with one important exception. Absolute bank size (the log of total assets) now becomes statistically significant with a negative sign. Hence, in the level regressions, larger banks tend to have lower CDS spreads. This change in results may be due to the fact that bank size changes only slowly over time, such that its effect cannot be gauged in a regression in first differences. If systemic risk is already fully captured by $-\Delta CoVaR$, the result is consistent with larger banks being less substitutable, which would support Hypothesis 3. This interpretation seems plausible because domestic credit is no longer significant in the level regression. If $-\Delta CoVaR$ does not fully capture size, as has been argued in a recent paper by Benoit, Colletaz, Hurlin, and Pérignon (2013), the negative effect of absolute bank size may also partially capture systemic risk. Moreover, as noted above, the effect could also be due to lower fundamental default risk of larger banks, e.g., due to diversification.

In columns (3) to (5) of Table 4.8, we repeat the three specifications of the full model (first differences with and without fixed effects and regression in levels) using the alternative measure of $-\Delta CoVaR$, which treats the United Kingdom and Switzerland as separate banking systems. All results remain virtually unchanged (apart from the coefficient of -VaR, which becomes insignificant in one regression).

Further robustness checks can be found in Appendix 4.D. First, we rerun the regressions without lagging any of the right-hand-side variables (both in first differences and levels, using both types of definition of CoVaR, see Table 4.9). Second, we substitute for our TBTS measure by using the ratio of total assets (rather than liabilities) to GDP as a measure of bank size (see Table 4.10 in Appendix 4.D). Finally, we use a milder winsorization for our risk variables $\Delta CoVaR$, VaR and z-score (2.5% instead of 5%, see Table 4.11 in Appendix 4.D). Interestingly, all regressions support Hypothesis 3, as $-\Delta CoVaR$ is always statistically significant. They also support Hypothesis 3, as the coefficient of the interaction term remains positive and is always statistically significant. The results are a bit less stable with regard to Hypothesis 3. In several regressions, neither the log of total assets nor domestic credit are statistically significant, which weakens the support for the substitutability hypothesis. Finally, the z-score becomes significant in some regressions, supporting its use as a measure of a bank's fundamental risk.

4.5 Wake-Up Call

Within our sample period, one can identify two key events that fundamentally changed the financial system: the onset of the financial crisis in 2007 and the failure of the US bank Lehman Brothers in 2008. In order to check for potential structural breaks, we divide our sample period into three sub-periods: first, a pre-crisis period from 2005 until July 2007; second, the crisis period from August 2007[12] until shortly before the meltdown of Lehman Brothers, i.e., until August 2008; finally, the post-Lehman period from September 2008 till the end of our sample. Note that the Lehman failure coincides with the trouble in the Icelandic banking system. We run our baseline regression (column (5) of Table 4.4), interacting all variables with dummy variables for each sub-period. The results are shown in Table 4.5. The first number column shows the estimated coefficients of the respective interaction terms, whereas the third column shows, for the crisis and post-Lehman period, the differences in estimated coefficients compared to the previous period and the corresponding p-values. This allows us to detect significant changes across periods.

In the pre-crisis period (top panel of Table 4.5), there is no indication that systemic risk was priced in CDS markets; the coefficient of $-\Delta CoVaR$ is negative, but insignificant. In contrast, the interaction effect of TBTS and country debt is already significant in the pre-crisis period. Domestic credit and GDP growth have the expected negative signs and are statistically significant in the pre-crisis period. Out of the bank risk variables, only ROAA has a significant effect on CDS spreads. Hence, in the pre-crisis period, higher bank returns translated into lower CDS spreads, whereas risk measures like leverage, z-score, or VaR are insignificant. This indicates that individual bank risk was not priced before the crisis, implying that CDS spreads were largely flat.

[12] Most observers date the beginning of the financial crisis on August 9, 2007.

However, with the beginning of the financial crisis, our measure of systemic importance ($-\Delta CoVaR$) almost doubles and becomes statistically significant (see medium panel of Table 4.5). Moreover, leverage and VaR become significant, whereas the significance of ROAA vanishes. This indicates that markets now became aware of banks' risks and priced in a lower default probability of systemically relevant institutions. The effects of domestic credit and GDP growth remain significant, but become more pronounced in this period. Importantly, the coefficient of absolute bank size is now significantly negative, suggesting that large banks were now considered to be bailed out with a larger probability. In light of the rescue of Bear Stearns, such expectations seem quite plausible (and more plausible than a decrease in the fundamental default risk of large banks).

In the last subperiod (bottom panel of Table 4.5), $-\Delta CoVaR$ has a somewhat reduced impact on CDS spreads compared to the crisis period (although this difference is not statistically significant). Similarly, the log of total assets is no longer significant, whereas the results on domestic credit remain unchanged. These results may reflect vanishing bail-out expectations in the light of rising sovereign debt problems. It may also partly be due to the non-bailout of Lehman Brothers, which put in question the 100% bail-out guarantee for systemic institutions and raised expectations of a tightening of future banking regulation (such as the introduction of bank resolution procedures), especially for systemic institutions.

The events can thus be seen as a double wake-up call. While the onset of the crisis in 2007 reminded investors of the risks in banking and of the fact that some banks were more likely to be bailed out than others, the Lehman breakdown and Icelandic crisis showed that the government may not always be able or willing to bail out even systemic institutions.

We checked the robustness of results by defining TBTS on the basis of bank total assets rather than liabilities and by employing a different level of the financial system in the definition of CoVaR, treating UK and Switzerland as separate systems (see Tables 4.12 and 4.13 in Appendix 4.D). The results are almost identical to those presented above. In particular, TSTF and individual bank risk was not priced before the crisis, but become significant in the crisis. The TBTS problem shows up in all subperiods. Finally, the effect of systemic risk is mitigated after the Lehman collapse.

The overall message remains: The two crisis events in August 2007 and September 2008 fundamentally changed the relationship between banks' CDS spreads and bank- and country-specific variables, especially those related to the TSTF problem.

Table 4.5: Pre-crisis, crisis, and post-Lehman analysis

		CDS		Difference to previous period	
	VARIABLES	Coef.	p-value	Coef.	p-value
(Pre-crisis)	$-\Delta CoVaR$	-3.413	(0.149)		
	TBTS	-71.13**	(0.0488)		
	TBTS * Debtratio	2.621***	(0.0022)		
	Debtratio	0.416	(0.749)		
	Log(Total assets)	-41.14	(0.124)		
	Domestic credit / GDP	-1.615**	(0.0497)		
	GDP growth	-18.70***	(0.0003)		
	Reserves / GDP	15.72	(0.927)		
	Leverage	0.556	(0.119)		
	ROAA	-10.34*	(0.0596)		
	Z-score	-0.0449	(0.767)		
	-VaR	0.913	(0.270)		
(Crisis)	$-\Delta CoVaR$	-6.415**	(0.0122)	-3.002	(0.133)
	TBTS	-61.17*	(0.0785)	9.956	(0.140)
	TBTS * Debtratio	2.483***	(0.0023)	-0.138	(0.288)
	Debtratio	0.496	(0.698)	0.0797	(0.432)
	Log(Total assets)	-46.80*	(0.0747)	-5.661**	(0.0491)
	Domestic credit / GDP	-1.705**	(0.0380)	-0.0897*	(0.0574)
	GDP growth	-22.30***	(0.0000)	-3.601*	(0.0587)
	Reserves / GDP	17.14	(0.920)	1.424	(0.903)
	Leverage	0.595**	(0.0281)	0.0387	(0.843)
	ROAA	-6.743	(0.200)	3.597	(0.250)
	Z-score	-0.445	(0.361)	-0.400	(0.377)
	-VaR	2.196*	(0.0618)	1.283	(0.166)
(Post-Lehman)	$-\Delta CoVaR$	-4.287*	(0.0795)	2.129	(0.554)
	TBTS	-56.83	(0.129)	4.349	(0.727)
	TBTS * Debtratio	1.956**	(0.0264)	-0.527	(0.111)
	Debtratio	1.087	(0.410)	0.591**	(0.0131)
	Log(Total assets)	-38.85	(0.123)	7.957	(0.184)
	Domestic credit / GDP	-1.899**	(0.0227)	-0.194	(0.115)
	GDP growth	-5.271**	(0.0149)	17.03***	(0.0004)
	Reserves / GDP	-53.37	(0.764)	-70.51**	(0.0265)
	Leverage	0.0729	(0.748)	-0.522*	(0.0719)
	ROAA	-0.407	(0.392)	6.337	(0.226)
	Z-score	-1.535	(0.129)	-1.090	(0.227)
	-VaR	1.831*	(0.0603)	-0.365	(0.818)
	Constant	-2.092***	(0.0095)	-2.092***	(0.0095)
	Observations	3,950		3,950	
	R-squared	0.467		0.467	
	Number of banks	72		72	
	Bank FE	YES		YES	
	Time FE	YES		YES	
	CoVaR	Continental		Continental	

Notes: OLS regressions in first differences for Equation (4.4) with bank fixed effects and time fixed effects and interacting all variables with a time dummy. (Pre-crisis) indicates a dummy that equals 1 before August 2007. (Crisis) indicates a dummy that equals 1 for the period August 2007 to August 2008. (Post-Lehman) indicates a dummy that equals 1 after September 2008. The first column shows the total coefficients for the respective period, the third column shows the differences to the previous period, the other two columns show the corresponding p-values in parentheses. Standard errors are clustered at the bank level throughout. ***, **, * indicate significance at the 1%, 5%, and 10% levels. TBTS is demeaned before taking first differences.

4.6 Conclusion

This chapter has analyzed the effect of systemic relevance as well as absolute and relative size on banks' CDS spreads. We argue that bank size is not a satisfactory measure of systemic risk, and differentiate the effect associated with bank size from the effect arising from the institution's systemic importance. To this end, we control for systemic risk using the $\Delta CoVaR$ measure introduced by Adrian and Brunnermeier (2011). Controlling for systemic risk, we then identify the too-big-to-save phenomenon by the interaction effect between a bank's size relative to GDP and the home country's fiscal situation. Finally, we also consider the effect of a bank's substitutability, which depends on the repercussions of bank distress on the real economy.

We find a significant decrease in CDS spreads for more systemically relevant institutions, which is consistent with the too-systemic-to-fail hypothesis. Markets expect that banks that are highly systemically relevant are more likely to receive governmental support in case of financial distress. Moreover, we find no significant effect of (relative) bank size in countries with a zero debt level, once we control for systemic risk. However, the effect of bank size increases in the home country's debt ratio, and the overall effect of relative bank size becomes positive already at moderate debt ratios. This result is consistent with the too-big-to-save hypothesis. Market participants appear to expect that, in countries with limited debt capacity, a bail-out is less likely the more funding is needed for it. Finally, there is some evidence that banks' substitutability also affects bail-out expectations. CDS spreads tend to be lower in bank-based countries. Moreover, in some regressions, absolute bank size also has a negative effect on CDS spreads. Given a bank's contribution to systemic risk within the financial sector, absolute bank size may capture the repercussions of bank distress on the real economy. However, the results on substitutability are not as robust as those on systemic relevance and on the too-big-to-save problem.

We further show that the relevance of TSTF changes over time. Before the financial crisis started in August 2007, we cannot find a significant effect of TSTF. However, we find a strong and significant effect of systemic relevance after the onset of the financial crisis, supporting the relevance of the TSTF problem in this period. The increased awareness of the TSTF problem may have resulted from the large number of bail-outs (before Lehman), which were justified by the prevention of contagion effects. The effect of TSTF weakens after September 2008, which may reflect vanishing bail-out expectations in the light of rising sovereign debt problems, but may also be due to the non-bailout of Lehman Brothers, which raised doubts about the bail-out guarantee for systemic institutions.

We interpret this sequence of events as a double wake-up call for investors. With the advent of the financial crisis in 2007, investors were reminded of the risks in banking and of the fact that some banks were more likely to be bailed out than others. The Lehman non-bail-out and the Icelandic crisis then showed that governments may not always be willing or able to bail out even systemic institutions.

This chapter hence adds in several ways to current policy discussions. First, it warns against a too strong reliance of policy makers on bank size as a measure of systemic importance. Bank size does not capture some aspects of systemic relevance, such as interconnectedness and correlation. Moreover, the effect of size on a bank's (perceived) bail-out probability is ambiguous due to the too-big-to-save problem. Second, the chapter supports the use of measures trying to explicitly capture the externalities from a bank's default on the remaining financial system, such as $\Delta CoVaR$. This chapter suggests that CDS markets indeed price in such externalities beyond the effects of bank size. The use of such measures also has the advantage of having rather modest data requirements. This chapter does not compare $\Delta CoVaR$ with other popular measures, such as the Marginal Expected Shortfall (MES, Acharya, Pedersen, Philippon, and Richardson (2012)) and the Systemic Risk Measure (SRISK, Brownlees and Engle (2011); Acharya, Engle, and Richardson (2012)), as was done by Benoit, Colletaz, Hurlin, and Pérignon (2013). Further research in this direction is certainly needed. Finally, this chapter stresses the time variation of systemic importance. Systemic relevance appears to vary strongly over time, especially in crisis times. Therefore, it may be misleading to define a list of systemic banks, as was done, for example, for the GSIBs (global systemically important banks), and to direct regulatory attention to these banks. Instead, one needs a constant surveillance of all banks to become aware of sudden build-ups of systemic risk.

Taken together, this chapter suggests that banks are not too big to fail, but they may be too systemic to fail and too big to save. Rather than being constant over time, the relative importance of these problems depends on economic circumstances. Even small banks may become too systemic to fail in a financial crisis. And even a small bank may become too big to save if the bank's home country is burdened with high levels of debt.

Appendix

4.A Estimation of CoVaR

We now briefly explain how to estimate CoVaR, which is defined as follows:[13]

$$CoVaR_q^{system|i} := VaR_q^{system}|VaR_q^i \tag{4.5}$$

The variable, on which the calculation of VaR and CoVaR is based, X^i, is in our case the return of market-valued total assets. Following closely the procedure proposed by Adrian and Brunnermeier (2011), we estimate CoVaR by using quantile regression, using a stress level of 1%. We use the extended version of CoVaR that models the time variation of the joint distribution of asset returns as a function of a number of state variables. We first generate VaR^i by regressing X^i on the lagged state variables, M_{t-1} in a quantile regression and generating predicted values:

$$VaR_t^i(q) = \hat{\alpha}_q^i + \hat{\gamma}_q^i M_{t-1}. \tag{4.6}$$

Then we regress X^{system} on individual returns, X^i, and the lagged state variables, M_{t-1} in a quantile regression at the 1% level, and generate predicted values at VaR_q^i:

$$CoVaR_t^i(q) = \hat{\alpha}_{1\%}^{system|i} + \hat{\beta}_{1\%}^{system|i} VaR_t^i(q) + \hat{\gamma}_{1\%}^{system|i} M_{t-1} \tag{4.7}$$

In the definition of our variables, we closely follow Adrian and Brunnermeier (2011). X^i, is the growth rate of market-valued total assets. Market equity is taken from Thomson Reuters Datastream and the leverage from Bureau van Dijk's Bankscope. Furthermore, we use the same vector of lagged state variables as Adrian and Brunnermeier, but exclude

[13]This exposition closely follows Adrian and Brunnermeier (2011)

the real estate sector return in excess of the market return because this variable is not available for the full set of countries.

Our measure of systemic risk, $\Delta CoVaR_t^i$, is defined as the difference between $CoVaR^i$ conditioned on distress times versus normal times of bank i, where normal times are characterized by the median. Hence, it is calculated as follows, using again the 1% stress level:

$$\Delta CoVaR_t^i(1\%) = CoVaR_t^i(1\%) - CoVaR_t^i(50\%) \tag{4.8}$$

$$= \hat{\beta}_{1\%}^{system|i}(VaR_t^i(1\%) - VaR_t^i(50\%)) \tag{4.9}$$

From these regressions, we obtain a panel of daily$\Delta CoVaR_t^i$, measuring the risk contribution of each individual institutions to the system. Note that $\Delta CoVaR_t^i$ is typically negative, with a more negative value indicating a greater contribution to systemic risk. For the ease of interpretation, we use $-\Delta CoVaR_t^i$ throughout the chapter, implying that an increase in this variable is to be interpreted as an increase in the contribution to systemic risk.

4.B Details on data construction

All data with daily frequency were winsorized at 5/95% (or 2.5/97.5% in the robustness check) before calculating monthly averages. For all data with yearly frequency, we use cubic spline interpolation to get monthly observations. The risk measures $\Delta CoVaR$ and VaR are multiplied by -1, such that a larger value indicates a higher contribution to systemic risk and a larger individual risk, respectively. For one bank in our sample, Glitnir, we observe a negative value of equity. Since this would correspond to an infinite leverage, we set the leverage for this bank to the maximum observed leverage in the remaining sample. For the same bank, we further observe implausibly large negative values of the return on average asset. Thus, we set eight observations with a return on average assets smaller than -100 to the remained minimum observed value. In all regression tables, we use the demeaned form of the TBTS variables (total bank liabilities/GDP or total bank assets/GDP).

Table 4.6: Description of variable construction and data sources

Variable name	Description	Data source
CDS	Single name 5-year senior CDS, winsorized at 5/95%	Datastream
$\Delta CoVaR$	Conditional VaR of market valued total financial assets, see definition in text and Adrian and Brunnermeier (2011), winsorized at 5/95%, multiplied by -1 throughout the chapter	Own calculation
TBTS	Total bank liabilities / GDP (in %)	BankScope & WDI
TBTS assets	Total bank assets / GDP (in %)	BankScope & WDI
Debtratio	Central government debt / GDP (in %)	WDI
Log(Total assets)	Log of bank total assets	BankScope
Domestic credit / GDP	Domestic credit provided by the banking sector / GDP (in %)	WDI
GDP growth	Annual growth rate of GDP (in %)	WDI
Reserves / GDP	Total reserves (including gold) (in % of GDP)	WDI
Leverage	Total bank assets / bank equity	BankScope
ROAA	Return on average assets (bank level)	BankScope
Z-score	Ratio of one plus the mean yearly stock return and the standard deviation of the yearly stock return, mean and standard deviation are calculated for a [t-261,t] window, winsorized at 5/95%	Own calculation & Datastream
VaR	Unconditional VaR of market valued total financial assets, winsorized at 5/95%, multiplied by -1 throughout the chapter	Own calculation
	for the VaR and CoVaR calculation:	
VIX	Implied volatility index	Chicago Board Options Exchange
Repospread	Difference between the 3-month repo rate and the 3-month bill rate	Bloomberg & Federal Reserve Board H.15 release
Termchange	Change in 3-month term government bill rate	Datastream & Federal Reserve Board H.15 release
Yieldchange	Change in the difference of the 10-year government bond yield and the 3-month bill rate	Datastream & Federal Reserve Board H.15 release
Creditchange	Change in the credit spread between BAA rated bonds and government bond yield (with same maturity of 10 years)	Datastream & Federal Reserve Board H.15 release

4.C List of Countries and Banks in the Sample

Table 4.7

Australia	1	Commonwealth	**Malaysia**	38	Malayan Bank
	2	Macquarie			
	3	National Australia Bank	**Netherlands**	39	ING Bank
	4	St. George		40	Rabobank
	5	Westpac Bank		41	SNS Bank
Austria	6	Erste Group Bank	**Norway**	42	DNB Bank
	7	Raiffeisenbank			
			Portugal	43	Banco Comercial de Portugues
Belgium	8	Ageas Fortis		44	Banco Espirito Santo
	9	Dexia			
	10	KBC Bank	**Singapore**	45	Oversea Chinese Bank
				46	United Overseas Bank
Denmark	11	Danske Bank			
			Spain	47	Banco Sabadell
France	12	BNP Paribas		48	Banco Santander
	13	Credit Agricole		49	Bankinter
	14	Natixis			
	15	Societe Generale	**Sweden**	50	Nordea
				51	Svenska
Germany	16	Commerzbank		52	Swedbank
	17	Deutsche Bank			
	18	IKB	**Switzerland**	53	Credit Suisse
	19	Bayerische Hypovereinsbank		54	UBS
Iceland	20	Glitnir	**United Kingdom**	55	Abbey Bank
	21	Kaupthing		56	Alliance Leicester
	22	Landsbanki		57	Barclays
				58	HBOS
India	23	Bank of India		59	HSBC
	24	Icici Bank		60	Lloyds
	25	Statebank of India		61	Royal Bank of Scotland
				62	Standard Chartered Bank
Ireland	26	Allied Irish Banks			
	27	Anglo Irish Bank	**USA**	63	Bank of America
	28	Bank of Ireland		64	Bear Stearns
				65	Capital One Bank
Italy	29	Banca Italease		66	Citigroup
	30	Banca Monte dei Paschi		67	Goldman Sachs
	31	Intesa Sao Paolo		68	JP Morgan Chase
	32	Unicredito		69	Merill Lynch
				70	Morgan Stanley
Japan	33	Mitsubishi UFJ		71	Wachovia
	34	Mizuho Bank		72	Washington Mutual
	35	Resona		73	Wells Fargo
	36	Shinsei Bank			
	37	Sumitomo Mitsui			

4.D Robustness

Table 4.8: Baseline regression without bank fixed, in levels, and using alternative CoVaR measure

VARIABLES	(1) CDS	(2) CDS	(3) CDS	(4) CDS	(5) CDS
$-\Delta CoVaR$	-5.073***	-2.241**	-4.099**	-4.236**	-2.276***
	(0.0052)	(0.0154)	(0.0158)	(0.0120)	(0.0092)
TBTS	-2.099	-5.452	-31.66	0.417	-5.177
	(0.959)	(0.453)	(0.330)	(0.992)	(0.474)
TBTS * Debtratio	1.734***	0.240**	1.937**	1.711***	0.238**
	(0.0079)	(0.0384)	(0.0199)	(0.0090)	(0.0397)
Debtratio	0.910	0.0888	0.744	0.897	0.0841
	(0.247)	(0.251)	(0.561)	(0.255)	(0.279)
Log(Total assets)	-39.86	-7.772*	-33.66	-39.92	-7.763*
	(0.112)	(0.0687)	(0.149)	(0.112)	(0.0696)
Domestic credit / GDP	-0.584	-0.0028	-1.441*	-0.585	0.0009
	(0.326)	(0.964)	(0.0642)	(0.325)	(0.989)
GDP growth	-7.601***	-1.151**	-7.814***	-7.623***	-1.138**
	(0.0002)	(0.0215)	(0.0004)	(0.0002)	(0.0229)
Reserves / GDP	-5.007	-11.83	-7.426	-4.094	-11.40
	(0.977)	(0.742)	(0.964)	(0.981)	(0.750)
Leverage	0.0562	0.0577	0.0624	0.0589	0.0559
	(0.784)	(0.368)	(0.764)	(0.773)	(0.392)
ROAA	-1.901***	0.0304	-0.705	-1.902***	0.0287
	(0.0014)	(0.801)	(0.179)	(0.0014)	(0.809)
Z-score	-0.231	-0.0447	-0.267	-0.240	-0.0505
	(0.350)	(0.724)	(0.275)	(0.333)	(0.688)
-VaR	1.298*	0.881**	1.143	1.202*	0.941**
	(0.0834)	(0.0369)	(0.119)	(0.0999)	(0.0286)
CDS (t-1)		0.905***			0.905***
		(0)			(0)
Constant	-2.140***	153.0*	-1.773**	-2.144***	152.6*
	(0.0034)	(0.0791)	(0.0460)	(0.0038)	(0.0803)
Observations	3,950	4,012	3,950	3,950	4,012
R-squared	0.439	0.941	0.441	0.439	0.941
Number of banks		72	72		72
Bank FE	NO	YES	YES	NO	YES
Time FE	YES	YES	YES	YES	YES
CoVaR	Continental	Continental	CH/UK	CH/UK	CH/UK

Notes: OLS regressions for Equation (4.4). The first and fourth column show results from a regression in first differences with time fixed effects, but without bank fixed effects. The second and fifth column show results for Equation (4.4) in levels including bank fixed effects and time fixed effects. Column 3 shows results from a regression in first differences with bank fixed effects and time fixed effects. CoVaR is calculated separately for Switzerland and UK in columns 3 to 5. Standard errors are clustered at the bank level throughout. p-value are given in parentheses. ***, **, * indicate significance at the 1%, 5%, and 10% levels. TBTS is demeaned before taking first differences. Sample sizes of different specifications differ due to data availability.

Table 4.9: Baseline regression without lagging right-hand-side variables

VARIABLES	(1) CDS	(2) CDS	(3) CDS	(4) CDS
$-\Delta CoVaR$	-5.019***	-3.820***	-5.087***	-3.869***
	(0.0078)	(0.0005)	(0.0050)	(0.0003)
TBTS	-31.48	-6.429	-28.12	-5.953
	(0.300)	(0.300)	(0.362)	(0.338)
TBTS * Debtratio	1.741**	0.228**	1.711**	0.225**
	(0.0240)	(0.0397)	(0.0273)	(0.0430)
Debtratio	-0.438	0.113	-0.444	0.105
	(0.800)	(0.123)	(0.798)	(0.154)
Log(Total assets)	-30.27	-7.130	-30.44	-7.105
	(0.132)	(0.112)	(0.131)	(0.114)
Domestic credit / GDP	-0.511	-0.0191	-0.506	-0.0127
	(0.618)	(0.757)	(0.622)	(0.838)
GDP growth	-7.754***	-1.311***	-7.757***	-1.288***
	(0.0006)	(0.0062)	(0.0006)	(0.0073)
Reserves / GDP	193.0	-12.13	193.2	-11.31
	(0.255)	(0.722)	(0.254)	(0.739)
Leverage	0.171	0.0568	0.171	0.0537
	(0.350)	(0.351)	(0.350)	(0.389)
ROAA	2.663***	0.0955	2.660***	0.0928
	(0.0000)	(0.280)	(0.0000)	(0.287)
Z-score	-0.687**	-0.108	-0.700**	-0.118
	(0.0235)	(0.434)	(0.0211)	(0.391)
-VaR	1.995**	1.504***	2.071**	1.603***
	(0.0152)	(0.0018)	(0.0107)	(0.0012)
CDS (t-1)		0.897***		0.896***
		(0)		(0)
Constant	-0.212	141.6	-0.122	140.7
	(0.770)	(0.118)	(0.866)	(0.120)
Observations	3,942	4,004	3,942	4,004
R-squared	0.429	0.942	0.429	0.942
Number of banks	72	72	72	72
Bank FE	YES	YES	YES	YES
Time FE	YES	YES	YES	YES
CoVaR	Continental	Continental	CH/UK	CH/UK

Notes: OLS regressions in first differences for Equation (4.4) with bank fixed effects and time fixed effects inserting all right-hand-side variables contemporaneously. The second and fourth column show results for the preceding regression in levels. CoVaR is calculated separately for Switzerland and UK in columns 3 and 4. Standard errors are clustered at the bank level throughout. p-value are given in parentheses. ***, **, * indicate significance at the 1%, 5%, and 10% levels. TBTS is demeaned before taking first differences. Sample sizes of different specifications differ due to data availability.

Table 4.10: Baseline regression with bank fixed effects and time fixed effects using the ratio of bank total assets to GDP as a measure of bank's size

VARIABLES	(1) CDS	(2) CDS	(3) CDS	(4) CDS	(5) CDS	(6) CDS
$-\Delta CoVaR$	-4.922***	-5.027***	-2.300**	-4.082**	-4.194**	-2.322***
	(0.0071)	(0.0056)	(0.0127)	(0.0163)	(0.0129)	(0.0080)
TBTS assets	-32.93	-9.888	-3.794	-30.35	-7.514	-3.517
	(0.297)	(0.789)	(0.588)	(0.340)	(0.839)	(0.614)
TBTS assets * Debtratio	1.730**	1.903***	0.160**	1.710**	1.883***	0.158*
	(0.0276)	(0.0047)	(0.0500)	(0.0298)	(0.0052)	(0.0519)
Debtratio	0.791	0.987	0.0993	0.773	0.973	0.0947
	(0.528)	(0.197)	(0.216)	(0.538)	(0.204)	(0.240)
Log(Total assets)	-33.08	-41.83	-6.828*	-33.13	-41.90	-6.822*
	(0.153)	(0.112)	(0.0789)	(0.153)	(0.111)	(0.0802)
Domestic credit / GDP	-1.445*	-0.669	0.0058	-1.446*	-0.670	0.0095
	(0.0649)	(0.249)	(0.922)	(0.0651)	(0.249)	(0.873)
GDP growth	-7.744***	-7.740***	-1.176**	-7.763***	-7.761***	-1.164**
	(0.0004)	(0.0001)	(0.0198)	(0.0004)	(0.0001)	(0.0211)
Reserves / GDP	-16.89	42.85	-7.979	-16.08	43.48	-7.531
	(0.918)	(0.796)	(0.835)	(0.922)	(0.794)	(0.843)
Leverage	0.0724	0.0914	0.0635	0.0751	0.0941	0.0618
	(0.733)	(0.683)	(0.321)	(0.722)	(0.673)	(0.342)
ROAA	-0.686	-1.032**	0.186**	-0.686	-1.035**	0.184**
	(0.197)	(0.0109)	(0.0106)	(0.197)	(0.0107)	(0.0107)
Z-score	-0.258	-0.235	-0.0378	-0.266	-0.244	-0.0436
	(0.291)	(0.342)	(0.765)	(0.276)	(0.325)	(0.729)
-VaR	1.247*	1.294*	0.914**	1.149	1.198	0.973**
	(0.0971)	(0.0840)	(0.0302)	(0.117)	(0.101)	(0.0235)
CDS (t-1)			0.906***			0.906***
			(0)			(0)
Constant	-1.739*	-2.035***	131.8*	-1.741*	-2.039***	131.5*
	(0.0501)	(0.0051)	(0.0923)	(0.0507)	(0.0057)	(0.0941)
Observations	3,950	3,950	4,012	3,950	3,950	4,012
R-squared	0.441	0.439	0.941	0.441	0.439	0.941
Number of banks	72		72	72		72
Bank FE	YES	NO	YES	YES	NO	YES
Time FE	YES	YES	YES	YES	YES	YES
CoVaR	Continental	Continental	Continental	CH/UK	CH/UK	CH/UK

Notes: OLS regressions for Equation (4.4). Columns 1 and 4 show results from a regression in first differences with bank fixed effects and time fixed effects. The second and fifth column show results from a regression in first differences with time fixed effects, but without bank fixed effects. Column 3 and column 6 show results for Equation (4.4) in levels including bank fixed effects and time fixed effects. CoVaR is calculated separately for Switzerland and UK in columns 4 to 6. Standard errors are clustered at the bank level throughout. p-value are given in parentheses. ***, **, * indicate significance at the 1%, 5%, and 10% levels. TBTS is demeaned before taking first differences. Sample sizes of different specifications differ due to data availability.

Table 4.11: Baseline regression with bank fixed effects and time fixed effects using a 2.5/97.5% winsorization

VARIABLES	(1) CDS	(2) CDS	(3) CDS	(4) CDS	(5) CDS	(6) CDS
$-\Delta CoVaR$	-5.320***	-5.397***	-2.527**	-4.816***	-4.901***	-2.499**
	(0.0050)	(0.0042)	(0.0225)	(0.0042)	(0.0034)	(0.0122)
TBTS	-32.24	-5.708	-3.599	-28.53	-2.348	-3.221
	(0.438)	(0.892)	(0.681)	(0.495)	(0.955)	(0.711)
TBTS * Debtratio	2.122*	2.276**	0.202*	2.069*	2.229**	0.198*
	(0.0554)	(0.0150)	(0.0546)	(0.0619)	(0.0172)	(0.0585)
Debtratio	0.892	1.507	0.188*	0.894	1.503	0.184
	(0.598)	(0.186)	(0.0967)	(0.598)	(0.187)	(0.104)
Log(Total assets)	-41.22	-50.44	-8.901	-41.28	-50.49	-8.952
	(0.198)	(0.153)	(0.109)	(0.198)	(0.152)	(0.109)
Domestic credit / GDP	-1.652	-0.669	-0.0085	-1.651	-0.669	-0.0046
	(0.101)	(0.388)	(0.919)	(0.101)	(0.390)	(0.956)
GDP growth	-9.020***	-9.324***	-1.303*	-9.030***	-9.337***	-1.280*
	(0.0092)	(0.0025)	(0.0602)	(0.0090)	(0.0024)	(0.0650)
Reserves / GDP	4.080	75.37	20.25	5.448	77.20	20.93
	(0.984)	(0.736)	(0.713)	(0.979)	(0.730)	(0.703)
Leverage	0.237	0.279	0.0879	0.241	0.283	0.0880
	(0.576)	(0.535)	(0.214)	(0.570)	(0.530)	(0.214)
ROAA	-1.031	-1.470**	0.153	-1.033	-1.475**	0.151
	(0.216)	(0.0422)	(0.416)	(0.216)	(0.0419)	(0.429)
Z-score	-0.282	-0.247	0.0285	-0.285	-0.251	0.0254
	(0.217)	(0.276)	(0.841)	(0.209)	(0.267)	(0.858)
-VaR	1.261*	1.320*	1.469***	1.262*	1.323*	1.528***
	(0.0943)	(0.0797)	(0.0028)	(0.0878)	(0.0730)	(0.0018)
L. CDS			0.903***			0.903***
			(0)			(0)
Constant	-1.382	-2.045**	165.1	-1.362	-2.027**	165.7
	(0.184)	(0.0196)	(0.135)	(0.193)	(0.0219)	(0.136)
Observations	3,950	3,950	4,012	3,950	3,950	4,012
R-squared	0.390	0.388	0.926	0.390	0.388	0.926
Number of banks	72		72	72		72
Bank FE	YES	NO	YES	YES	NO	YES
Time FE	YES	YES	YES	YES	YES	YES
CoVaR	Continental	Continental	Continental	CH/UK	CH/UK	CH/UK

Notes: OLS regressions for Equation (4.4). Columns 1 and 4 show results from a regression in first differences with bank fixed effects and time fixed effects. The second and fifth column show results from a regression in first differences with time fixed effects, but without bank fixed effects. Column 3 and column 6 show results for Equation (4.4) in levels including bank fixed effects and time fixed effects. CoVaR is calculated separately for Switzerland and UK in columns 4 to 6. Standard errors are clustered at the bank level throughout. p-value are given in parentheses. ***, **, * indicate significance at the 1%, 5%, and 10% levels. TBTS is demeaned before taking first differences. Sample sizes of different specifications differ due to data availability.

Table 4.12: Pre-crisis, crisis, and post-Lehman analysis using the ratio of bank total assets to GDP as a measure of bank's size

		CDS		Difference to previous period	
	VARIABLES	Coef.	p-value	Coef.	p-value
(Pre-crisis)	$-\Delta CoVaR$	-3.424	(0.148)		
	TBTS assets	-68.17*	(0.0532)		
	TBTS assets * Debtratio	2.346***	(0.0039)		
	Debtratio	0.445	(0.729)		
	log(Total Assets)	-40.48	(0.127)		
	Domestic Credit / GDP	-1.618*	(0.0507)		
	GDP growth	-18.56***	(0.0003)		
	Reserves / GDP	8.975	(0.959)		
	Leverage	0.579	(0.107)		
	ROAA	-10.29*	(0.0609)		
	Z-score	-0.0464	(0.759)		
	-VaR	0.917	(0.268)		
(Crisis)	$-\Delta CoVaR$	-6.426**	(0.0120)	-3.002	(0.132)
	TBTS assets	-58.35*	(0.0856)	9.817	(0.136)
	TBTS assets * Debtratio	2.209***	(0.0043)	-0.137	(0.280)
	Debtratio	0.526	(0.677)	0.0814	(0.424)
	log(Total Assets)	-46.14*	(0.0764)	-5.658**	(0.0485)
	Domestic Credit / GDP	-1.709**	(0.0387)	-0.0908*	(0.0557)
	GDP growth	-22.18***	(0.0000)	-3.616*	(0.0575)
	Reserves / GDP	10.38	(0.952)	1.405	(0.904)
	Leverage	0.617**	(0.0233)	0.0376	(0.848)
	ROAA	-6.727	(0.201)	3.565	(0.254)
	Z-score	-0.440	(0.366)	-0.393	(0.385)
	-VaR	2.208*	(0.0605)	1.291	(0.163)
(Post-Lehman)	$-\Delta CoVaR$	-4.251*	(0.0825)	2.175	(0.545)
	TBTS assets	-54.20	(0.139)	4.154	(0.734)
	TBTS assets * Debtratio	1.699**	(0.0435)	-0.510	(0.116)
	Debtratio	1.115	(0.392)	0.588**	(0.0139)
	log(Total Assets)	-38.17	(0.126)	7.967	(0.185)
	Domestic Credit / GDP	-1.905**	(0.0231)	-0.196	(0.112)
	GDP growth	-5.259**	(0.0151)	16.92***	(0.0004)
	Reserves / GDP	-58.33	(0.744)	-68.71**	(0.0322)
	Leverage	0.0831	(0.716)	-0.534*	(0.0640)
	ROAA	-0.391	(0.414)	6.336	(0.226)
	Z-score	-1.527	(0.131)	-1.088	(0.227)
	-VaR	1.837*	(0.0591)	-0.371	(0.815)
	Constant	-2.056**	(0.0109)	-2.056**	(0.0109)
	Observations	3,950		3,950	
	R-squared	0.466		0.466	
	Number of banks	72		72	
	Bank FE	Yes		Yes	
	Time FE	YES		YES	
	CoVaR	Continental		Continental	

Notes: OLS regressions in first differences for Equation (4.4) with bank fixed effects and time fixed effects and interacting all variables with a time dummy. (Pre-crisis) indicates a dummy that equals 1 before August 2007. (Crisis) indicates a dummy that equals 1 for the period August 2007 to August 2008. (Post-Lehman) indicates a dummy that equals 1 after September 2008. The first column shows the total coefficients for the respective period, the third column shows the differences to the previous period. Standard errors are clustered at the bank level throughout. p-value in parentheses. ***, **, * indicate significance at the 1%, 5%, and 10% levels. TBTS is demeaned before taking first differences.

Table 4.13: Pre-crisis, crisis, and post-Lehman analysis using alternative CoVaR measure

		CDS		Difference to previous period	
	VARIABLES	Coef.	p-value	Coef.	p-value
(Pre-crisis)	$-\Delta CoVaR$	-2.879	(0.168)		
	TBTS assets	-70.44*	(0.0542)		
	TBTS assets * Debtratio	2.621***	(0.0024)		
	Debtratio	0.390	(0.765)		
	log(Total Assets)	-41.18	(0.121)		
	Domestic Credit / GDP	-1.614**	(0.0499)		
	GDP growth	-18.73***	(0.0003)		
	Reserves / GDP	19.18	(0.911)		
	Leverage	0.559	(0.116)		
	ROAA	-10.56*	(0.0534)		
	Z-score	-0.0514	(0.732)		
	-VaR	0.842	(0.309)		
(Crisis)	$-\Delta CoVaR$	-5.791**	(0.0220)	-2.912	(0.117)
	TBTS assets	-60.32*	(0.0870)	10.11	(0.160)
	TBTS assets * Debtratio	2.493***	(0.0024)	-0.128	(0.343)
	Debtratio	0.473	(0.712)	0.0822	(0.415)
	log(Total Assets)	-46.74*	(0.0731)	-5.568*	(0.0535)
	Domestic Credit / GDP	-1.706**	(0.0378)	-0.0922*	(0.0550)
	GDP growth	-22.34***	(0.0000)	-3.611*	(0.0610)
	Reserves / GDP	19.39	(0.910)	0.205	(0.986)
	Leverage	0.594**	(0.0311)	0.0351	(0.856)
	ROAA	-6.818	(0.194)	3.746	(0.221)
	Z-score	-0.465	(0.339)	-0.413	(0.361)
	-VaR	2.122*	(0.0669)	1.280	(0.168)
(Post-Lehman)	$-\Delta CoVaR$	-3.702*	(0.0959)	2.090	(0.544)
	TBTS assets	-59.07	(0.122)	1.248	(0.923)
	TBTS assets * Debtratio	2.001**	(0.0234)	-0.492	(0.136)
	Debtratio	1.071	(0.418)	0.598**	(0.0107)
	log(Total Assets)	-38.66	(0.122)	8.082	(0.173)
	Domestic Credit / GDP	-1.898**	(0.0228)	-0.192	(0.119)
	GDP growth	-5.302**	(0.0142)	17.04***	(0.0003)
	Reserves / GDP	-50.91	(0.775)	-70.29**	(0.0284)
	Leverage	0.0733	(0.746)	-0.521*	(0.0817)
	ROAA	-0.406	(0.393)	6.412	(0.220)
	Z-score	-1.552	(0.127)	-1.088	(0.231)
	-VaR	1.792*	(0.0664)	-0.330	(0.835)
	Constant	-2.081***	(0.0098)	-2.081***	(0.0098)
	Observations	3,950		3,950	
	R-squared	0.466		0.466	
	Number of banks	72		72	
	Bank FE	Yes		Yes	
	Time FE	YES		YES	
	CoVaR	UK/CH		UK/CH	

Notes: OLS regressions in first differences for Equation (4.4) with bank fixed effects and time fixed effects and interacting all variables with a time dummy. (Pre-crisis) indicates a dummy that equals 1 before August 2007. (Crisis) indicates a dummy that equals 1 for the period August 2007 to August 2008. (Post-Lehman) indicates a dummy that equals 1 after September 2008. The first column shows the total coefficients for the respective period, the third column shows the differences to the previous period. Standard errors are clustered at the bank level throughout. p-value in parentheses. ***, **, * indicate significance at the 1%, 5%, and 10% levels. TBTS is demeaned before taking first differences.

Chapter 5

Conclusion

The experience with past periods of financial turmoil documents that policymakers often try to fix banking regulation in response to severe financial distress. After the 2007-09 financial crisis, too, many regulatory measures have been introduced. This thesis investigates three policy measures that have been heavily discussed in the aftermath of this most recent financial crisis.

The second chapter focusses on the debate regarding an increase in capital requirements. It is shown in a general equilibrium framework with heterogeneous banks that the overall effect of stricter capital requirements remains ambiguous in the short run: Higher capital requirements reduce moral hazard at the individual bank level. However, with a selection problem among agents, higher regulatory equity might introduce another unintended consequence. Banks are not allowed to absorb the excess supply of debt funding when a regulator demands a higher capital adequacy and additional equity cannot be raised immediately. Therefore, some agents with a lower success probability start doing bank business such that the average quality of the banking sector deteriorates. The chapter further shows that the effect of regulatory changes differ in the degree of heterogeneity. The negative selection effect is the stronger the larger the differences in banks' ability due to, for example, specialization. Therefore, since the overall effect of stricter banking regulation remains ambiguous in the short run, it will require further research to investigate the long-run general equilibrium outcome of stricter capital requirements.

In the third chapter, the thesis discusses the role of the credit-to-GDP gap as the determining factor for setting a countercyclical capital buffer. It provides evidence for a positive correlation between banks' contribution to systemic risk and an increasing credit-to-GDP gap, but it also reveals that banks seem to actively invest in assets with higher risks in times of excessive credit. Therefore, while the implemented regulatory measure of a countercyclical capital buffer based on the credit-to-GDP gap aims to mitigate the problem of an exogenous increase in bank systemic risk, regulators should also consider the expansion of bank asset risk. If one interprets the excessive provision of credit as increasing competition, our finding of increasing risk appetite would be in line with the theoretical predictions of Rajan (1994) and Aikman, Haldane, and Nelson (2015). However, more research in this field is clearly necessary. While this chapter provides a first bank-level insight into these different types of risk, we need a clear understanding about the drivers of these risks in order to address the problem of pro-cyclicality in a coherent and effective manner.

Chapter four of this thesis investigates the determinants of market expectation for the probability of a bank bailout. It shows that bank size is not a satisfactory measure for the market's perceived bailout probability of banks, but that these probabilities depend on a bank's systemic importance. Quite the contrary, bank size may actually reduce bailout expectations if the institution's home country is burdened with high levels of debt. We therefore show that banks are not too-big-to-fail, but might be too-systemic-to-fail and too-big-to-save.

Thus, the thesis provides important implications for the future conduct of banking regulation. First, it highlights the need for the analysis of general equilibrium effects arising from regulatory measures rather than relying on partial equilibrium outcomes. In this way, the thesis adds to the discussion on the optimal amount of regulatory equity by showing that the general equilibrium outcome of increasing capital requirements in banking might have an ambiguous effect on the stability of the financial system (chapter 2). While an increase in regulatory equity comes along the beneficial features of reducing moral hazard, mitigating prompt corrective actions and protecting bank's creditors against losses, it might also lead to a substitution between good and bad banks. This mechanism plays also an important role in the policy debate on shadow banks. Policymakers should therefore be aware of possible unintended consequences when they attempt to stabilize the financial sector by making individual banks more resistant. Thus, it requires further research on this topic before regulatory measures are implemented. A theoretical model that analyzes the effect of increasing capital requirements in the long run where both liquidity and solvency issues are addressed as well as for empirical evidence on the relationship between increasing equity requirements and financial stability is needed to shed more light on this issue. As a second lesson of this thesis, we highlight the need for proper banking regulatory measures to rely on causality rather than on correlations. The countercyclical capital buffer, as it was introduced in the Basel III framework, is a case in point. It was decided to base the countercyclical buffer rate on the credit-to-GDP gap due to empirical findings that the credit-to-GDP gap is the best predictor of financial distress. There is, however, no understanding about why this measure performs well in predicting financial crises. While this thesis provides a first important bank-level insight into banks' systemic risk and banks' asset risk in times of a large credit-to-GDP gap, there is need to further analyze and combat the root of the increase in risk during an excessive credit boom. A second case in point of building regulation on causality rather than on correlation is the introduction of systemic risk buffers. While former literature suggested that there is a competitive advantage for large banks arising from implicit guarantees, we show that that bailout probabilities depend on a bank's systemic importance rather than its size, and that the two concepts do not necessarily coincide. Hence, policymakers should not rely on bank size as a measure of systemic importance to internalize the negative externalities and the distortions of diminishing market discipline of systemically important institutions. In this way, the systemic risk buffer that has been introduced in the Basel III regulation is a proper course. The Basel Committee requires global systemically important financial institutions to have higher loss absorbency capacity, where the status of being systemically important is identified based on a methodology that includes both quantitative indicators and qualitative elements (see Basel Committee on Banking Supervision (2011)). Overall, this thesis has shown some strong weaknesses of the ongoing attempt to stabilize the financial system. New regulatory measures should be derived based on proper economic theories with a clear empirical evidence on the mechanism of the implemented measure. Hence, there is much to understand before we can shape the future of banking regulation in a way that prevents society from the next Great Depression.

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